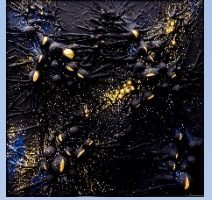
The Archimedes Experiment Theoretical progresses

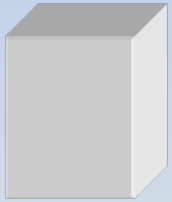
- INFN_sezione di Naples – Laboratorio Fisica della Gravitazione Univ. Federico II
- INFN sezione di Roma1 – Univ. La Sapienza Roma
- INO sezione di Napoli
- Université de Aix-Marseille Centre de Physique Théorique de Luminy
  Institut Universitaire de France
- EGO European Gravitational Observatory - Italy

L. Rosa – Orosei 2019-04-29

Scientific Motivations



Since the birth of Quantum Mechanics the question rised if the zero-point energy gravitates (Nerst, Pauli…) –The first attempt of by Pauli



$$\sum \frac{1}{2}\hbar\omega \quad \Rightarrow \quad \infty$$

Pauli inserted a cut-off on the minimal length (electron classical radius) and inserted the value of the energy density in the static Eisntein solution

The expected radius of the Universe was: 31 Km!

Cosmological constant problem: "why the universe exhibits a vacuum energy density much smaller than the one resulting from application of quantum mechanics and equivalence principle?" (Weinberg **Rev.Mod.Phys. 61 (1989) 1-23**)

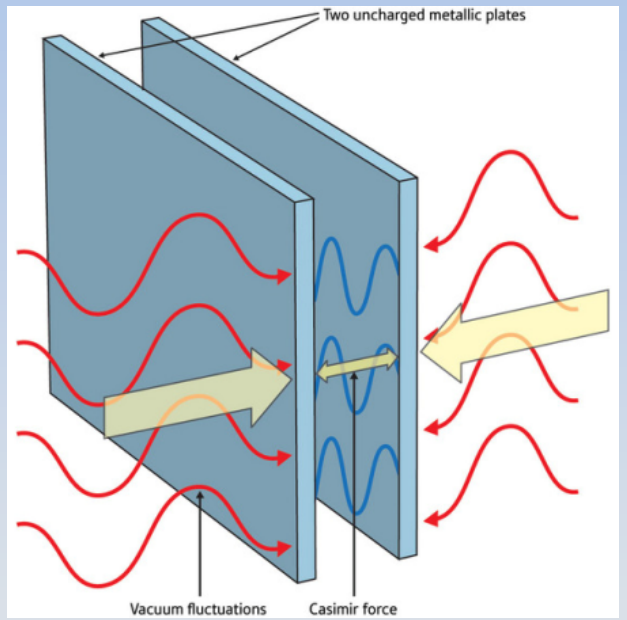
Main question still open with no experimental answer

Does vacuum fluctuations gravitate or not?

Does vacuum pressure exhibits the red-shift ?

The reality of macroscopic vacuum fluctuation.

The Casimir effect It is derived considering the zero point e.m. energy contained in a Casimir cavity, i.e. in the volume defined by two perfectly reflecting parallel plates



$$E = \sum \frac{1}{2}\hbar\omega$$

If the plates are perfectly reflecting the modes that can oscillate must have discrete wavenumbers on vertical axes $k_z = np/a$ while all values are allowed for k_x e k_y

$$E = \frac{hcL^2}{2} \sum_{n=-\infty}^{n=\infty} \int \frac{d^2k}{(2\pi)^2} \sqrt{k^2 + \left(\frac{n\pi}{a}\right)^2} \longrightarrow \infty$$

The regularization is made by determing the Casimir Energy as the change in energy when the plates are at distance "a" with respect to the plates having a→infinity

$$E_{reg} = E(a) - E(\infty)$$

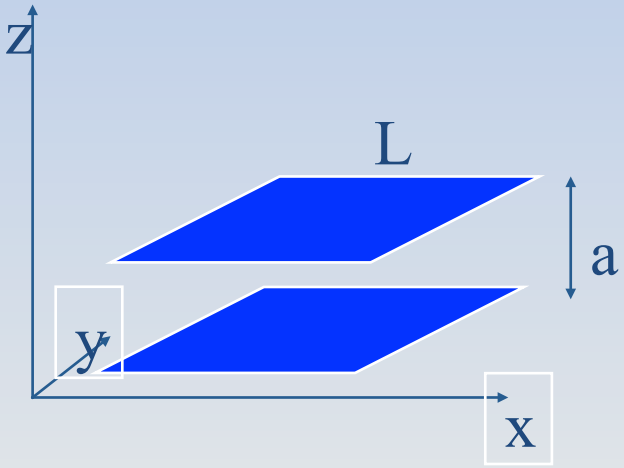
- **Casimir Energy** $E_{reg} = -\frac{\pi^2 L^2 hc}{720 a^3}$

- **Casimir Pressure** $P_C = \frac{1}{L^2}\frac{\partial U}{\partial a} = -\frac{\pi^2 hc}{240 a^4}$ $= 1.3\text{x}10^{-3}\ \text{N/m}^2(1\text{mm}/a^{4)}$

First prediction: Casimir 1948
First measure (force): Sparnay 1956
First measure (force) in the original flat-flat configuration: Carugno: 2002
Presently tested (force) with an accuracy of 0.5% (Mohideen: 2005)
(No problems in QFT in flat space-time)

Weighing the vacuum

The idea is to weigh a **rigid** Casimir cavity when the vacuum energy is modulated by changing the reflectivity of the plates. The forces along z are

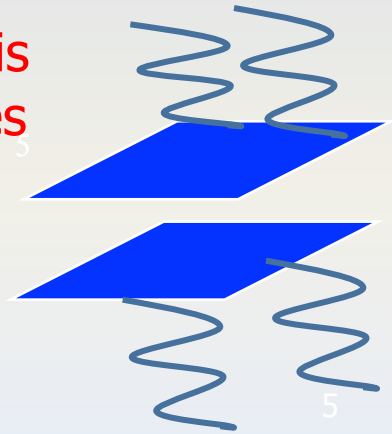


$$\begin{cases} F_{\text{sup}} = -F_C \\ F_{\text{inf}} = F_C\left(1+\delta\phi\right)+\dfrac{|E_C|}{c^2}g \end{cases}$$

$$\delta\phi = \frac{g\cdot a}{c^2} \quad \Leftrightarrow \quad \text{difference of gravitational potential between the plates}$$

$$\vec{F}_{tot} = \frac{|E_C|}{c^2}g\ \hat{z}$$

The total force is directed upward an it is equal to the weigh of the vacuum modes that are removed from the cavity



IN ANALOGY WITH ARCHIMEDES FORCE

Pressure red-shift

A simple summation of the lower force and upper force on the plates would bring to a somewhat unespected result:

$$F_C = L^2 \frac{\pi \hbar c}{240 a^4}$$

$$F_{\inf} + F_{\sup} = F_C(1+\delta\phi) + \frac{|E_C|}{c^2} g - F_C = 4\frac{|E_C|}{c^2} g$$

$$E_C = -L^2 \frac{\pi \hbar c}{720 a^3}$$

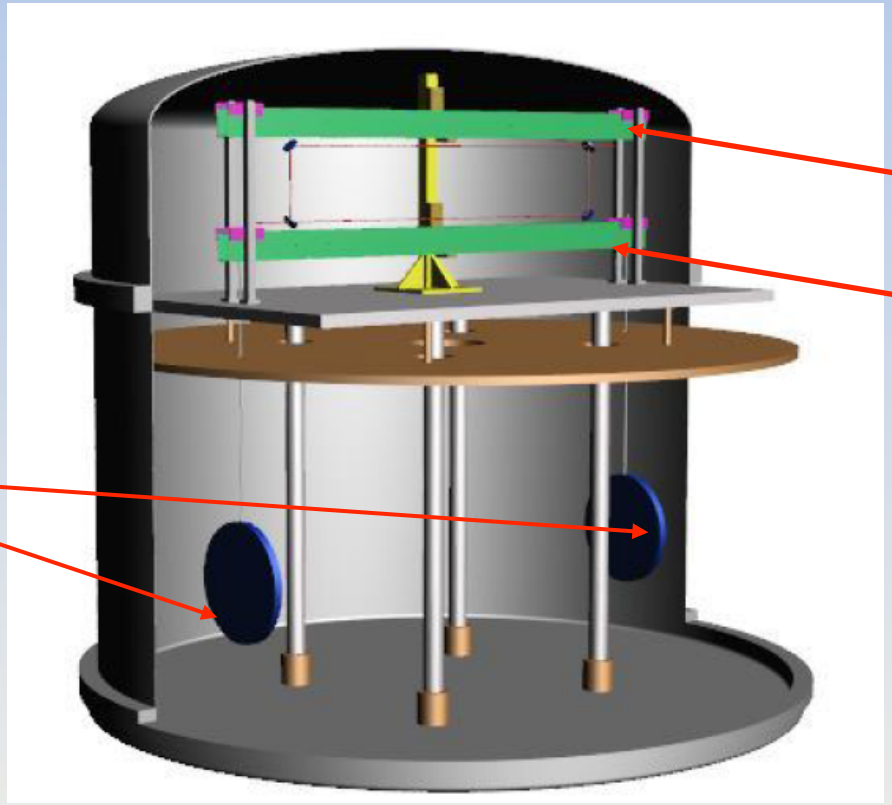
The lower vacuum «photons» must exert a bigger force because the force will be red-shifted when reaching the same level of upper plate → in the experiment the sum must be done taking into account the red-shift becuase the cavity is rigid and hanged in a unique point - (<u>for this effect our measurement is a null measurement</u>)

$$\begin{cases} F_{\sup} = F_C \\ F_{\inf} = -F_C(1+\delta\phi) + \frac{|E_C|}{c^2} g \end{cases} \Leftrightarrow \vec{F}_{tot} = \frac{|E_C|}{c^2} g \, \hat{z}$$

E. Calloni L. Rosa et.al. Phys. Letters A, 297, 328-333, (2002)
G. Bimonte, E. Calloni , G. Esposito, L. Rosa - Phys. Rev D 74, 085011 (2006)

S. A. Fulling et al. Phys. Rev. D76:025004 (2007)
K.A. Milton et al. J. Phys. A 41:164052 (2008)
G. Bimonte, E. Calloni et. al. Phys.Rev.D76:025008, (2007)

Measurement Method: A cryogenic balance in a very quiet seismic environment



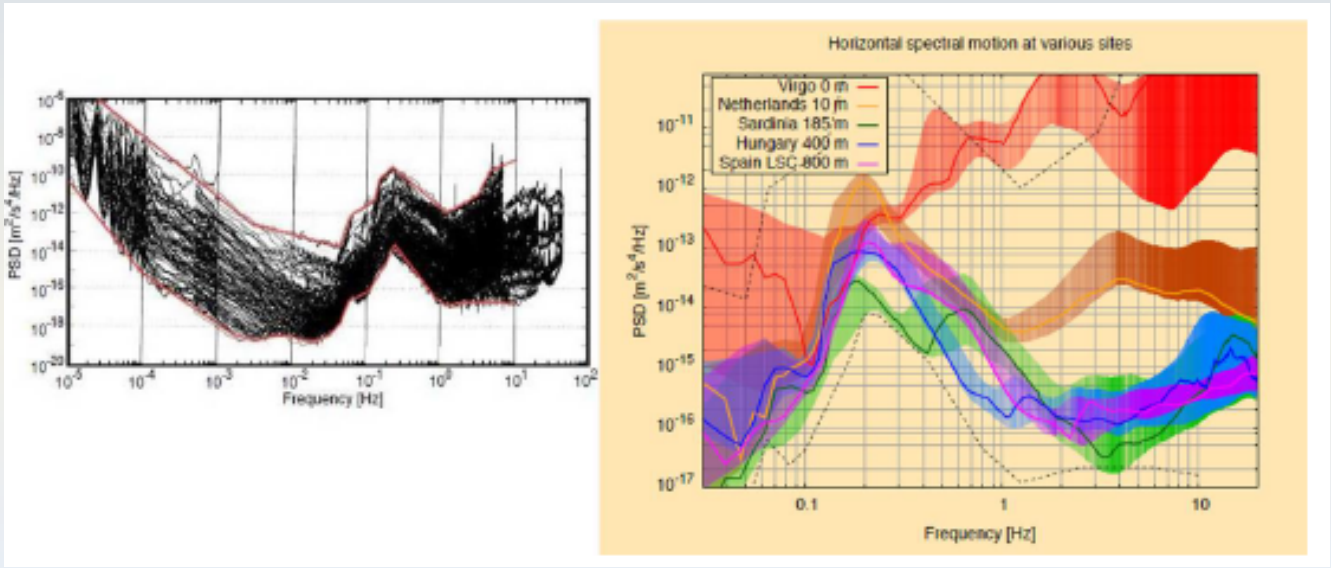
Use a beam-balance → modulate the force by modulating the temperature of the superconductor so that it makes transitions bewteen Normal and superconducting state - Expected modulation of force $F = 4*10^{-16}$ N

For the Archimedes experimental techniques see P. Puppo Talk on Wednesday
For details on optics and mechanics see L. Errico Talk on Friday

A quiet site!
Low seismic – No antropic noise

Sindaco	Mario Calia (lista civica) dall'11-6-2012
Territorio	
Coordinate	40°28′N 9°29′E
Altitudine	521 m s.l.m.
Superficie	148,72 km²
Abitanti	1 407[1] (31-7-2016)
Densità	9,46 ab./km²
Comuni confinanti	Bitti, Dorgali, Galtellì, Irgoli, Loculi, Lodè, Onani, Orune, Siniscola

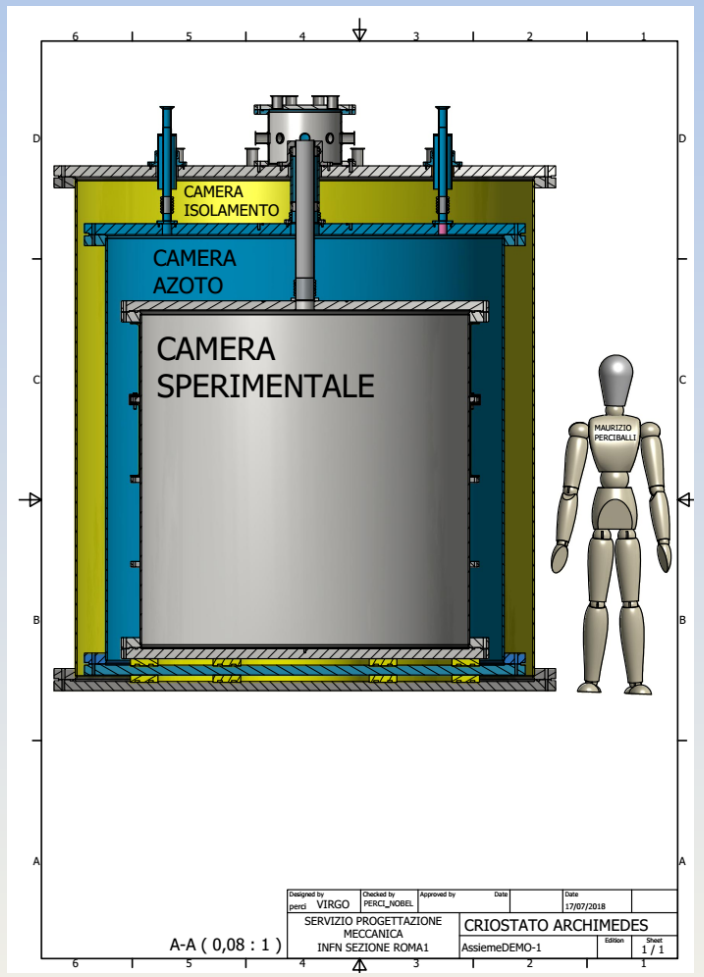
SOS-Enattos Mine



Seismic Measurements By Virgo and ET collaborations

SAR-GRAV underground Lab

The laboratory SAR-GRAV is presently under construction in the Sos-Enattos mine – A visit is possible next Thursday - Archimedes will be the first experiment installed – First step toward ET (third generation GW Detector)



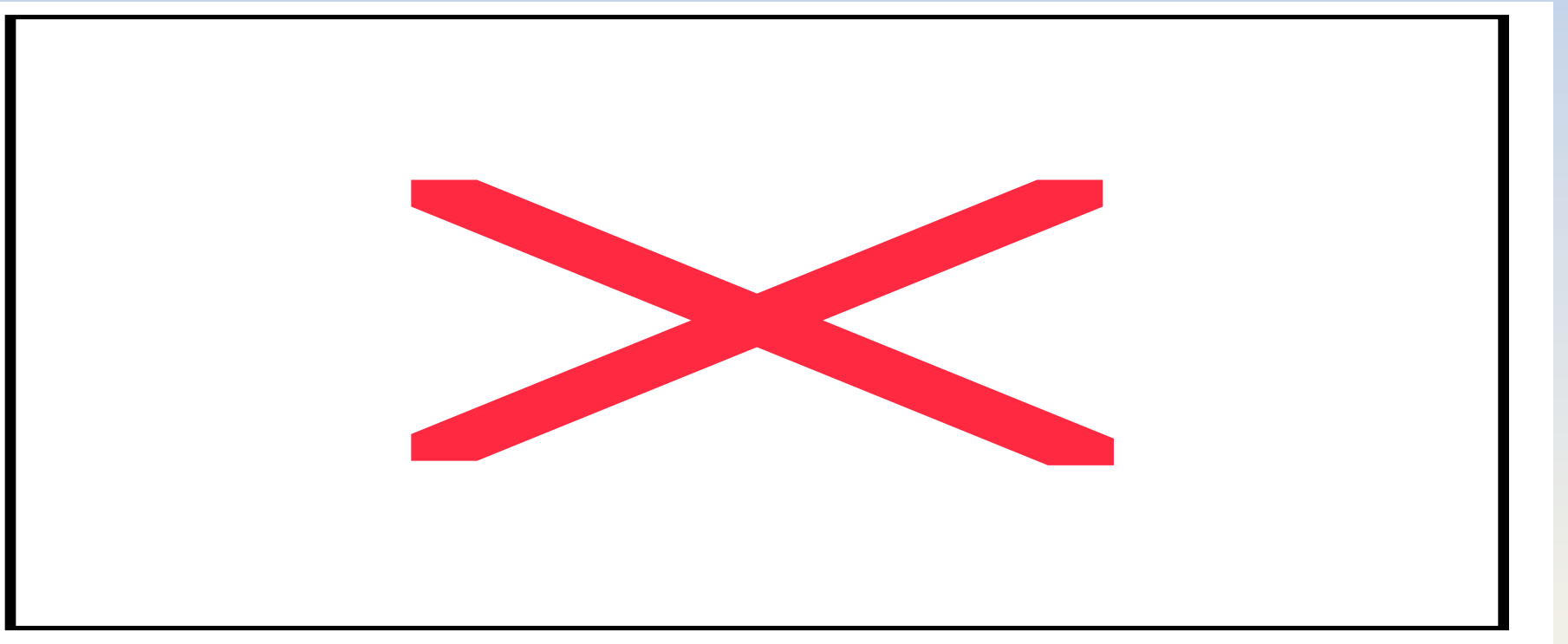
Cryostat design

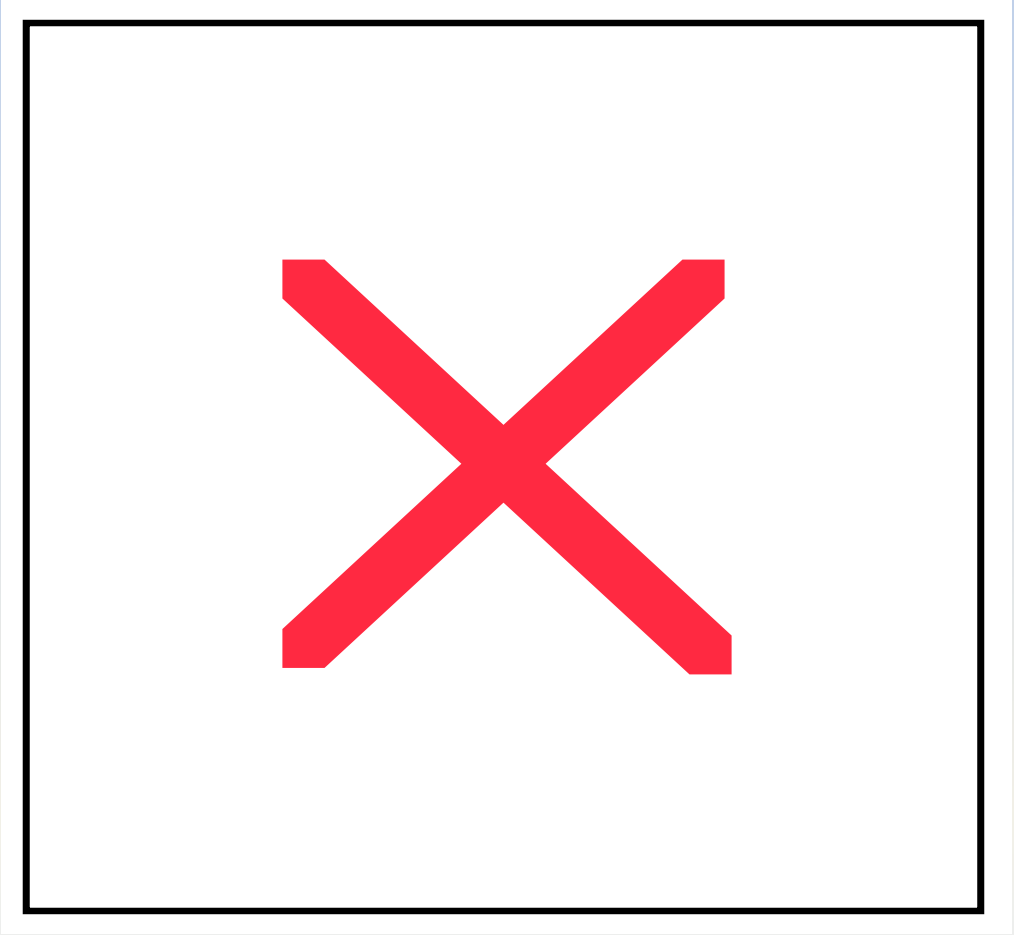
For details on cryogenic system see P. Rapagnani Talk on Friday
For underground site characterization and relationship with ET see dedicated sessions

Theoretical progresses

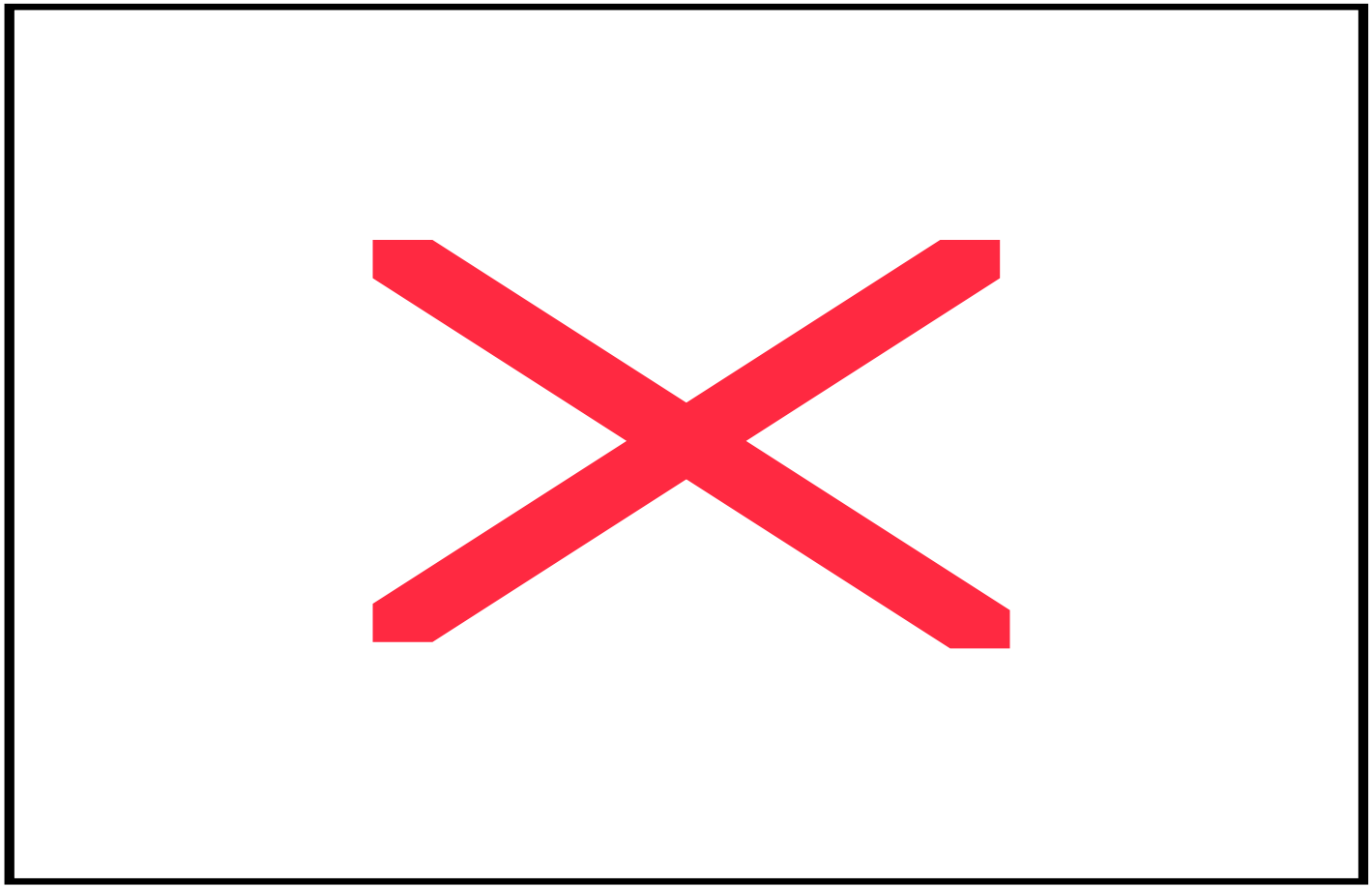
R. Bimonte, E. Calloni L. R. et al -Towards measuring variations of Casimir energy by a superconducting cavity
Phys.Rev.Lett. 94 (2005) 180402
L. Rosa et al - Casimir energy for two and three superconducting coupled cavities: Numerical calculations
Eur.Phys.J.Plus 132 (2017) no.11, 478
L. Rosa et al – Casimir energy for layered superconductors (in preparation -2019)

Theoretical progresses

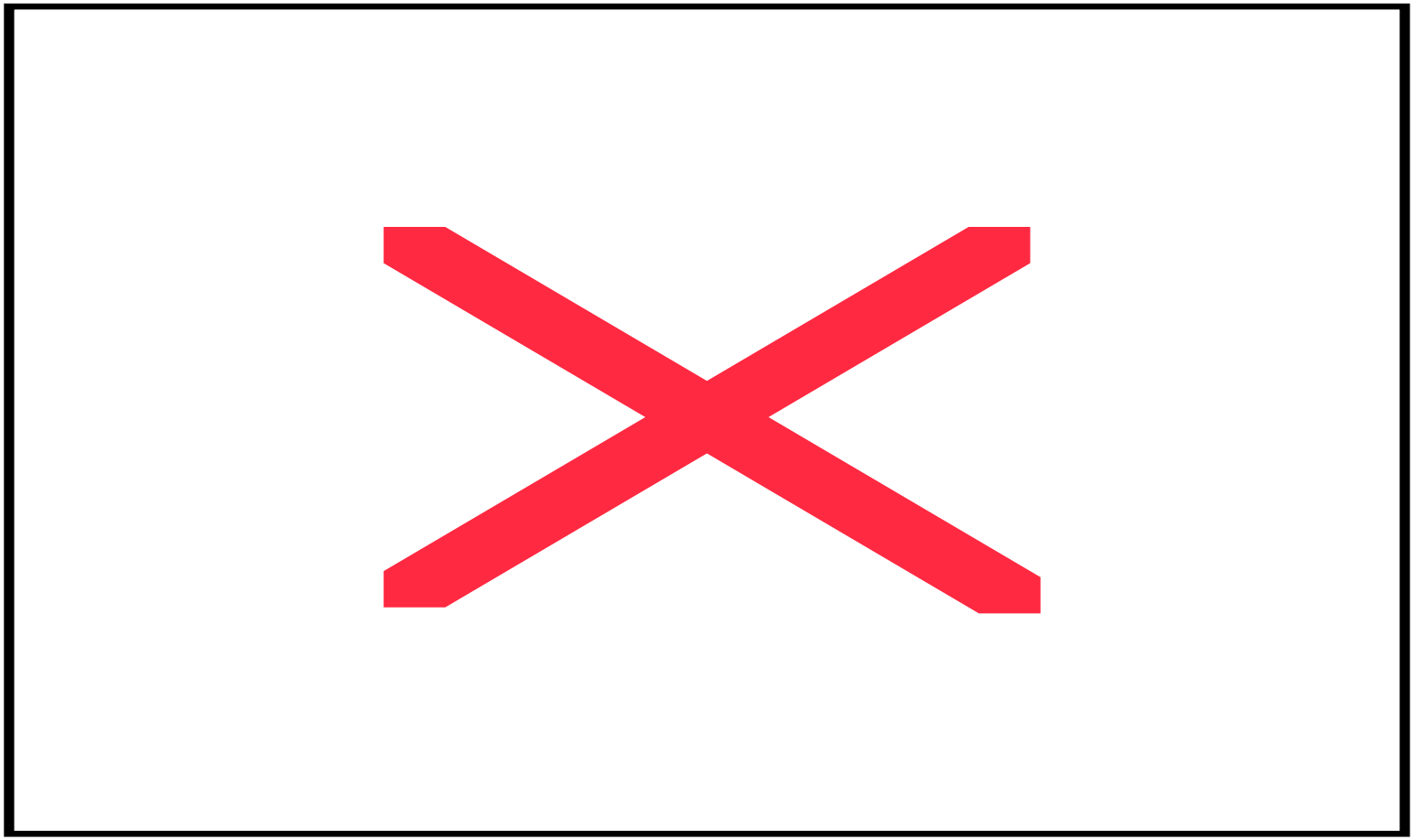




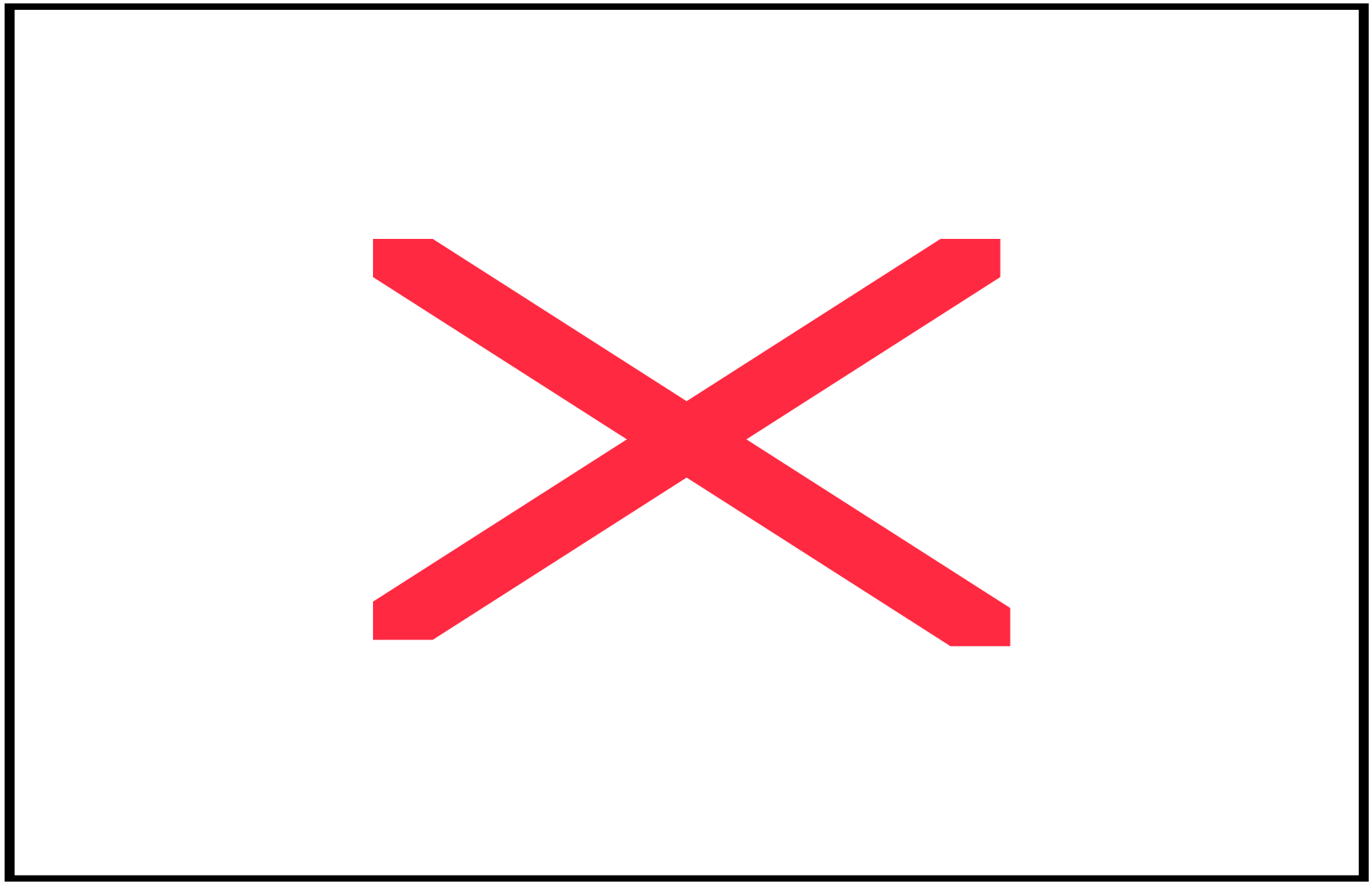
CASIMIR ENERGY (BCS)



2-CAVITIES



n-CAVITIES



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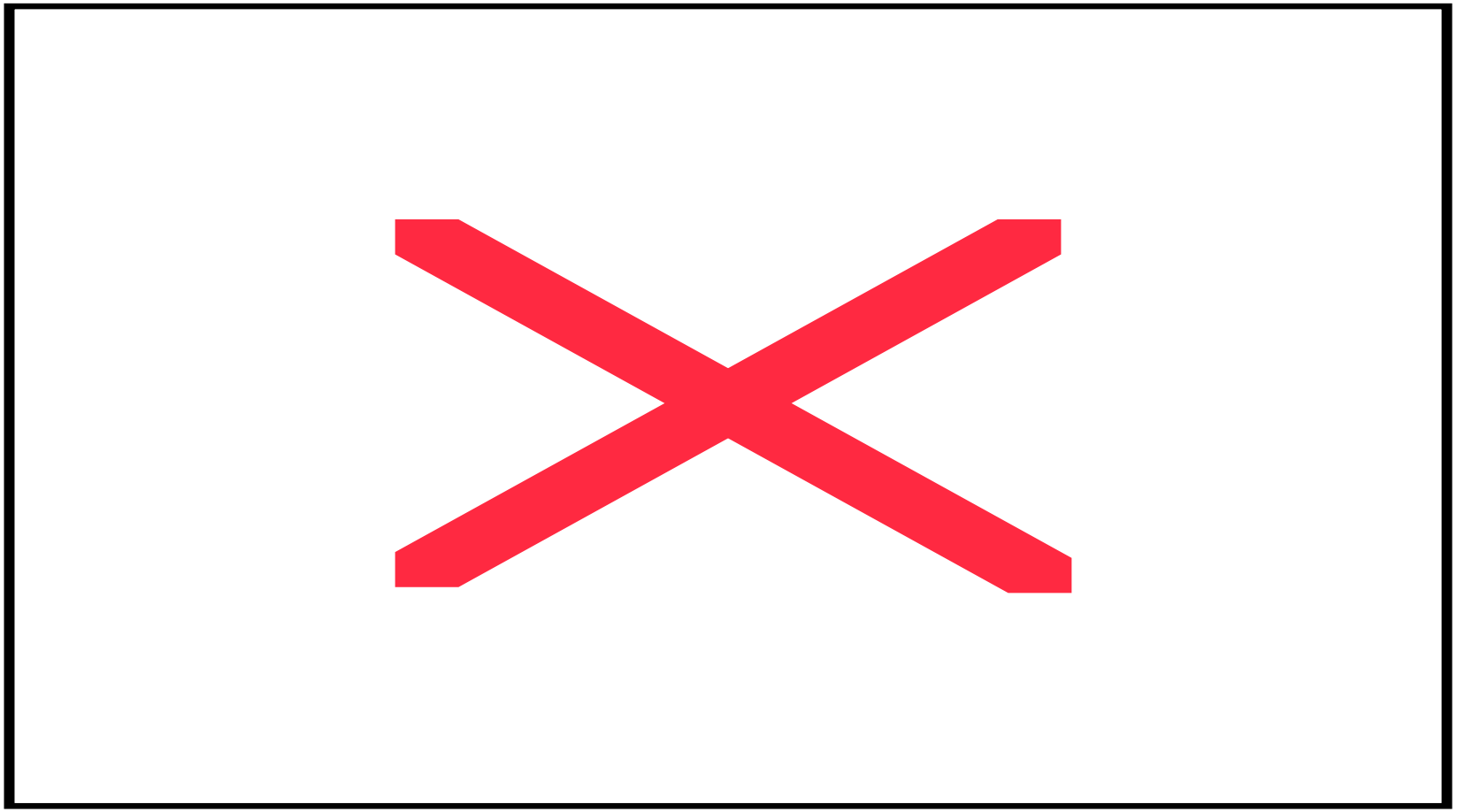

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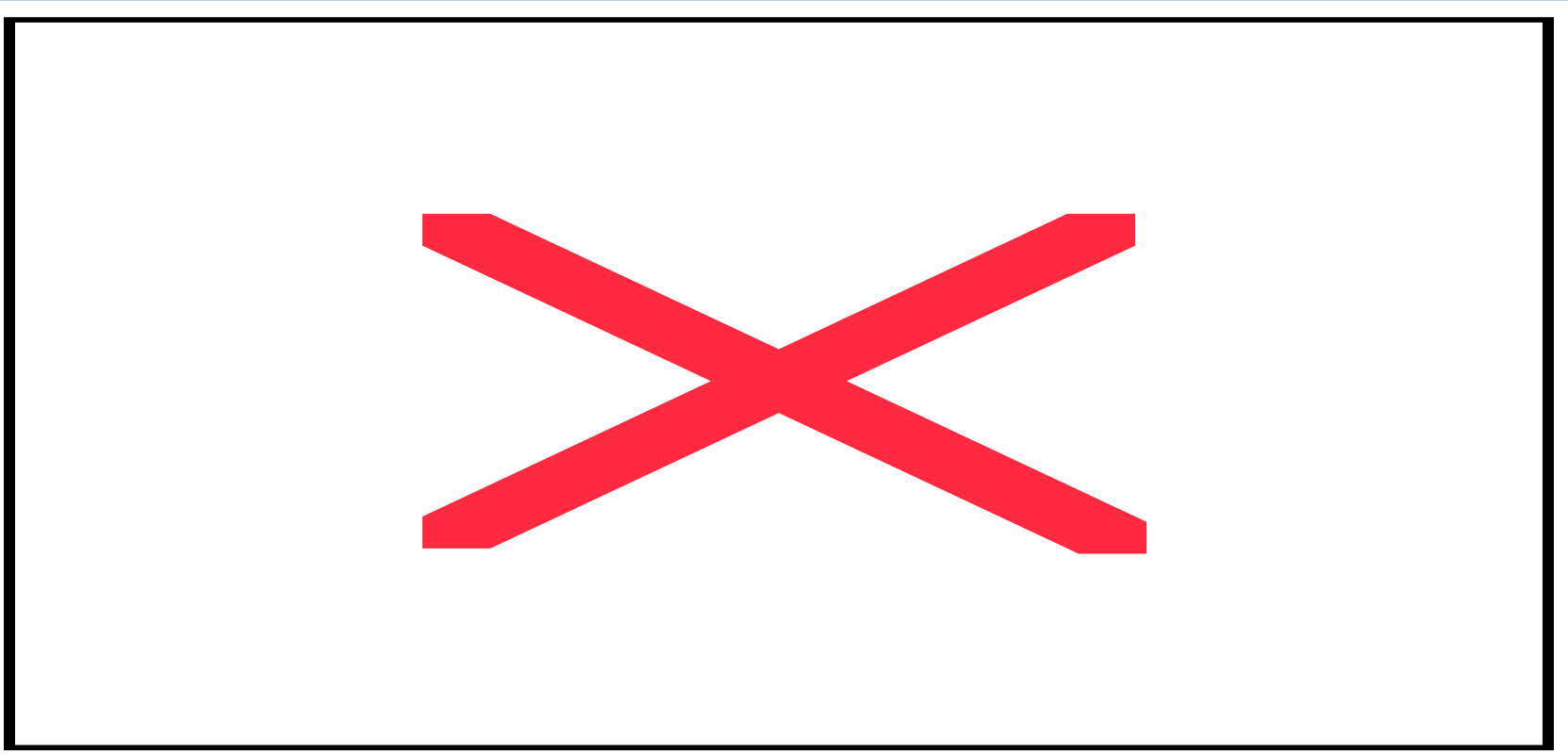
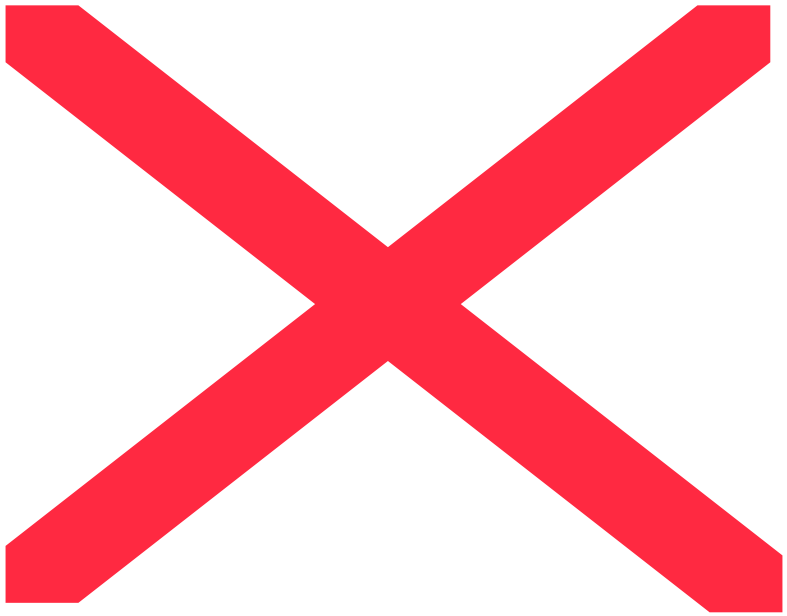
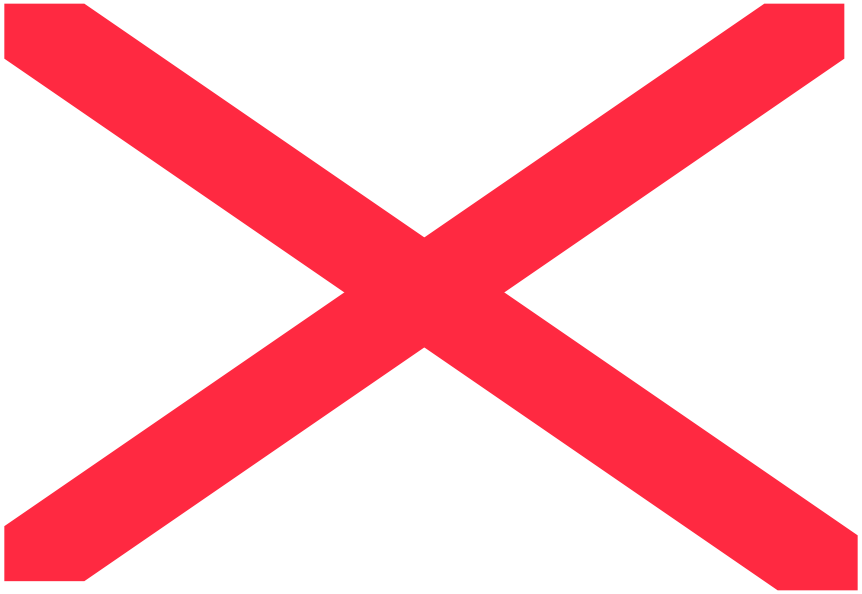
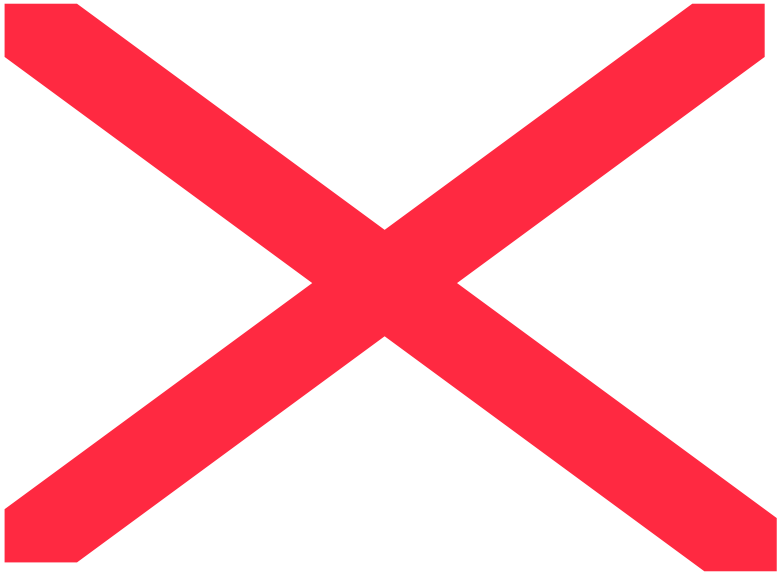
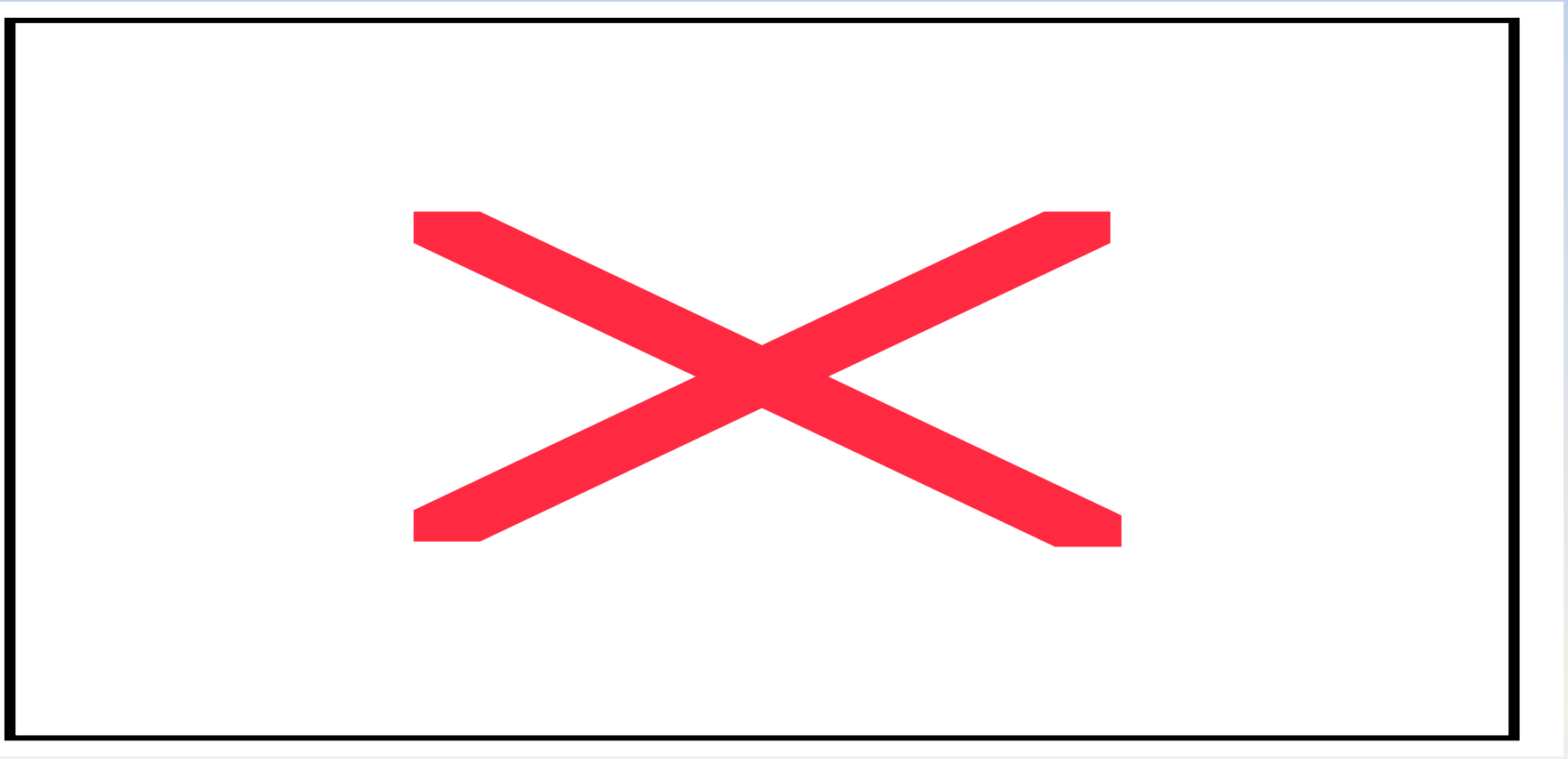




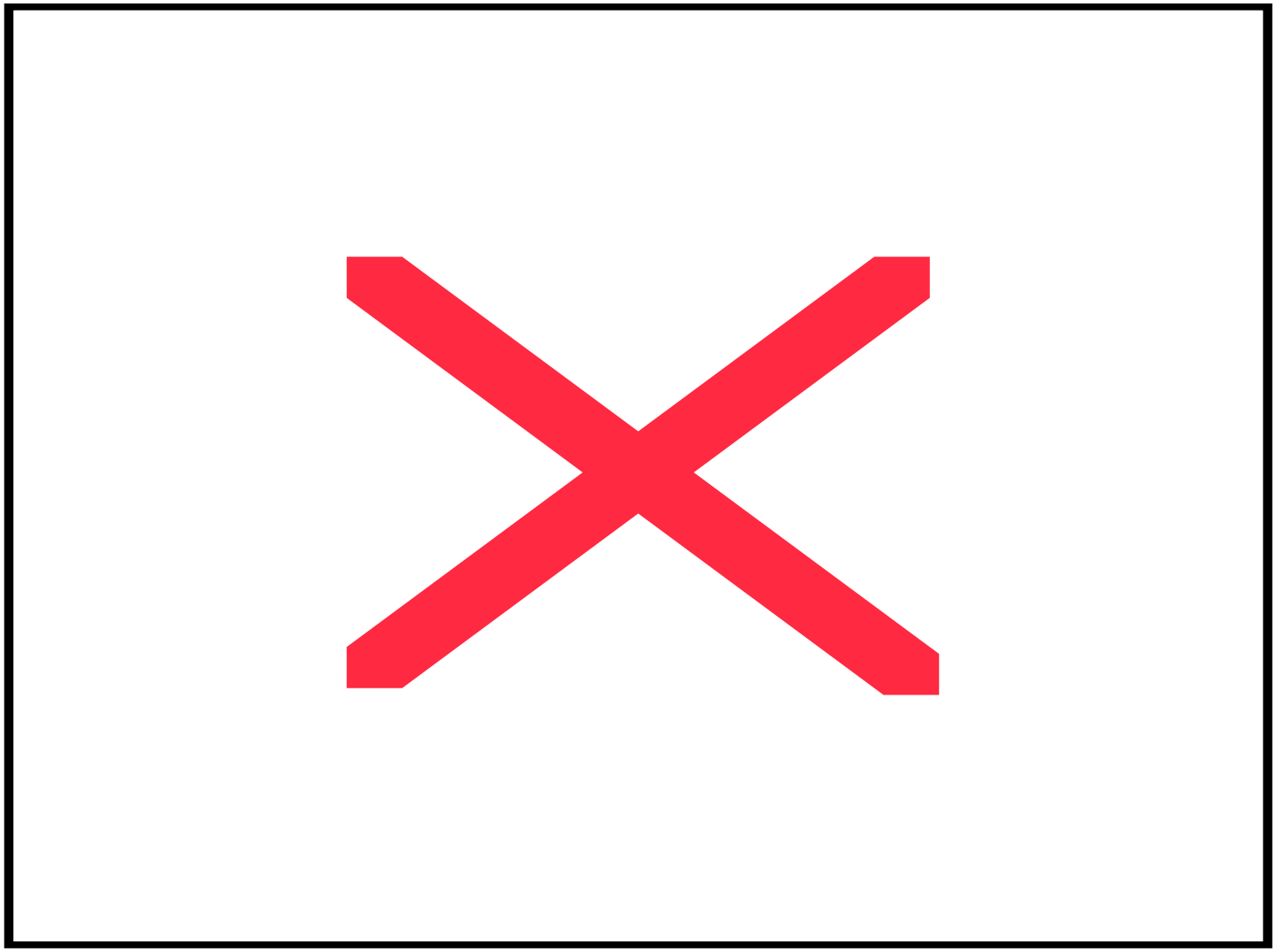




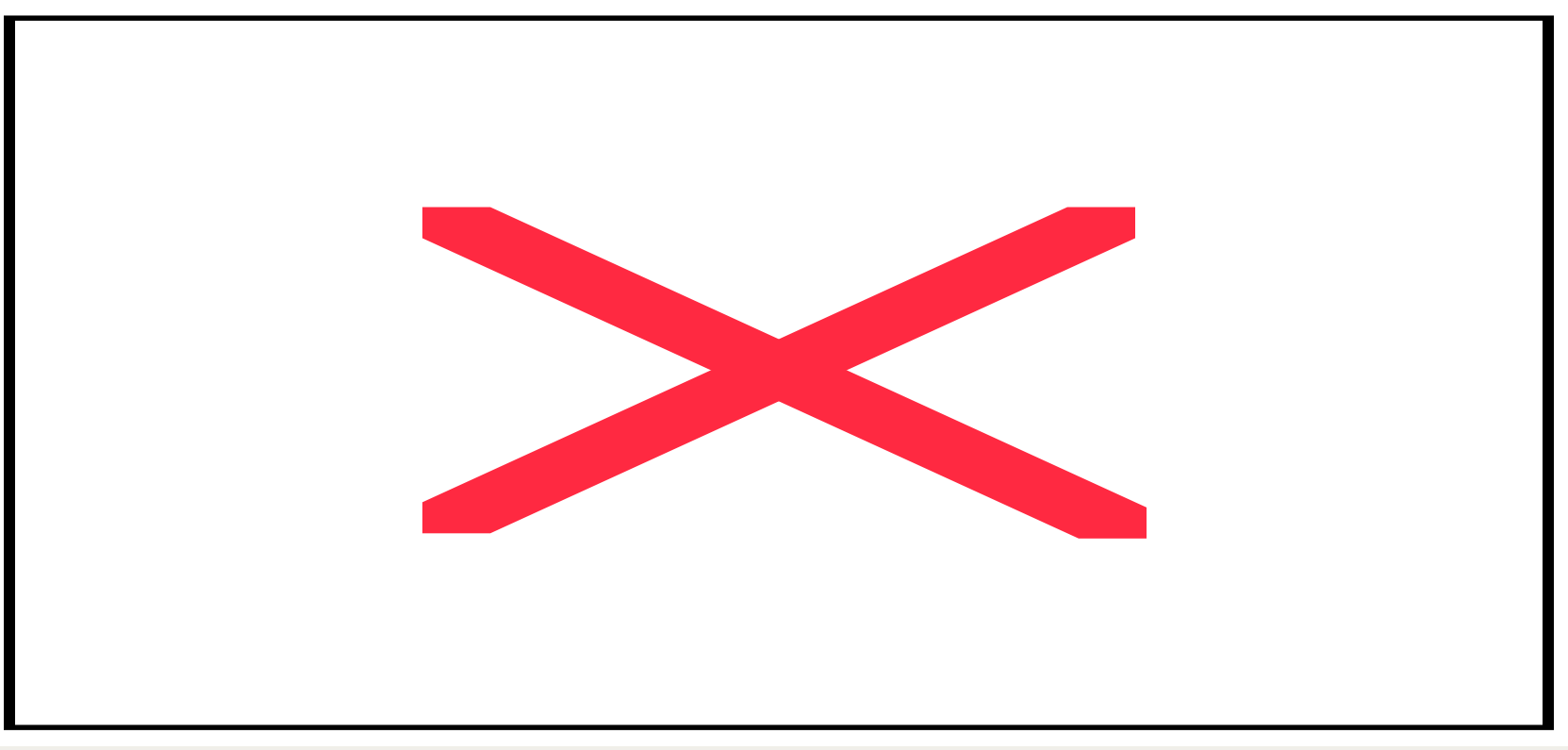
Proposal : weighing the condensation energy of Type II superconductors and modulate the transition to modulate the weigth

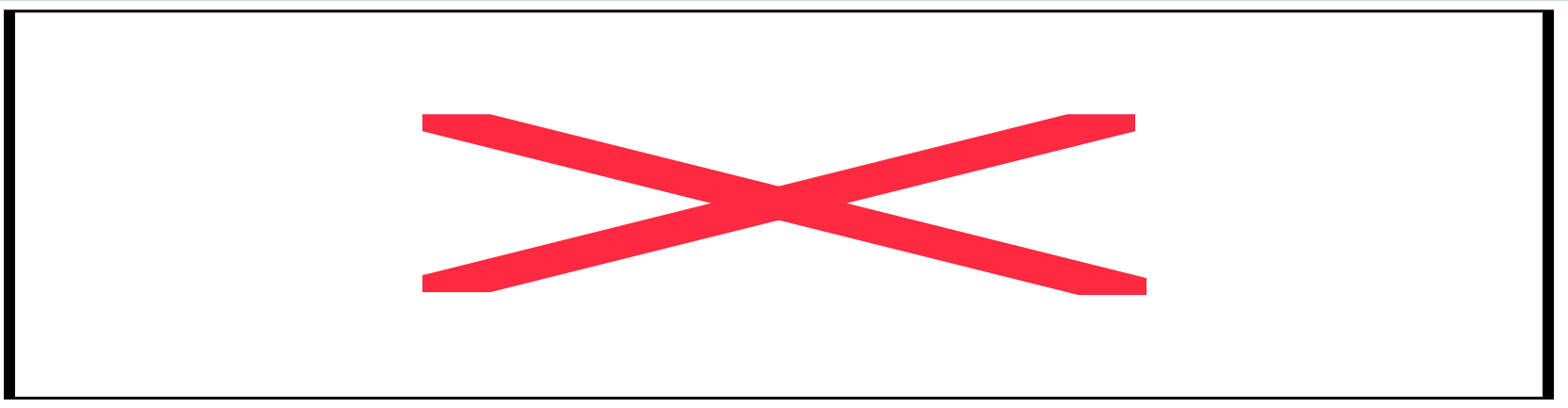


HIGH X SUPERCONDUCTOR

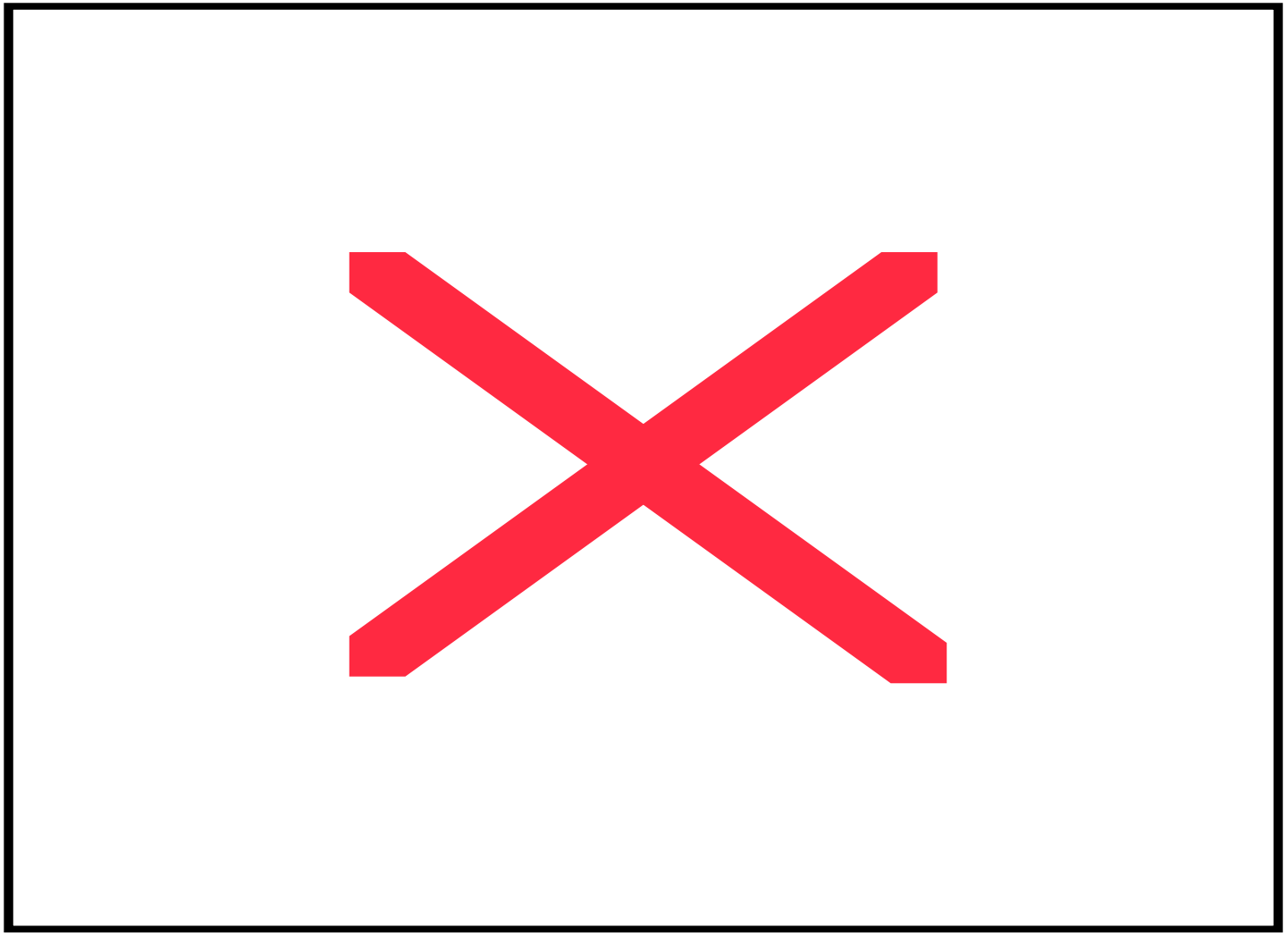


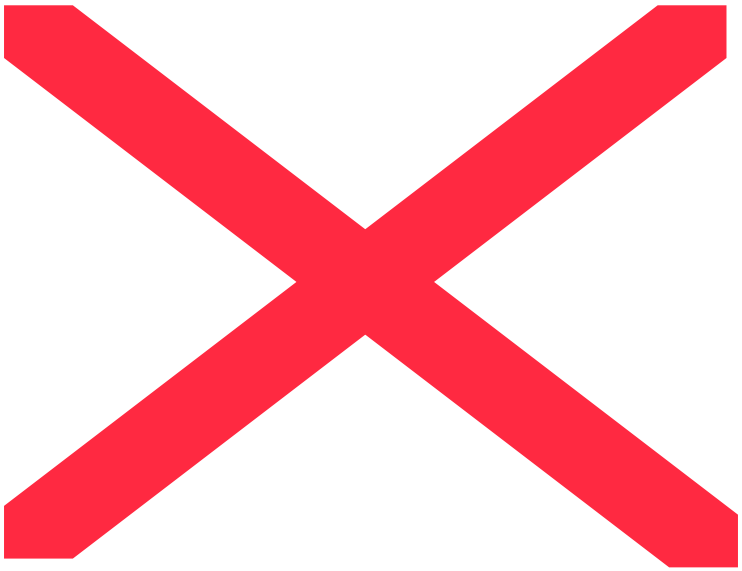
M.T.D. Orlando, A.N. Rouver, J.R. Rocha, and A.S. Cavichini, Phys. Lett. A 382(2018) 1486

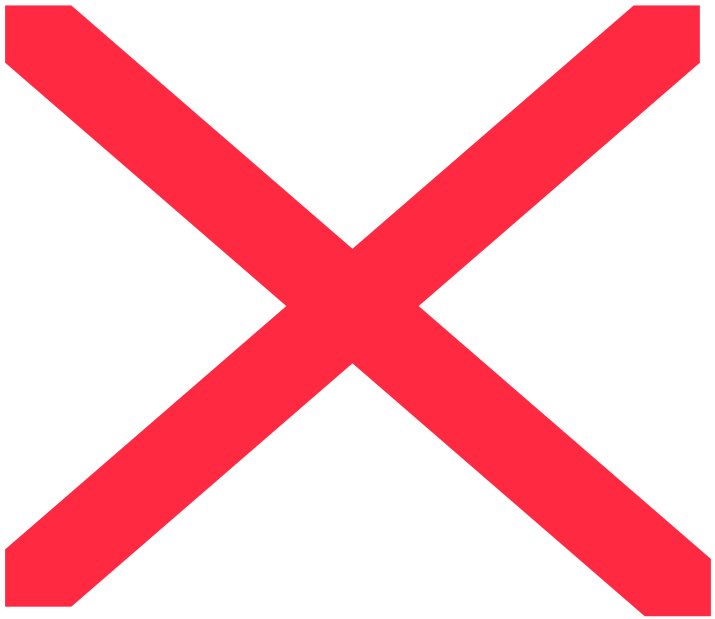


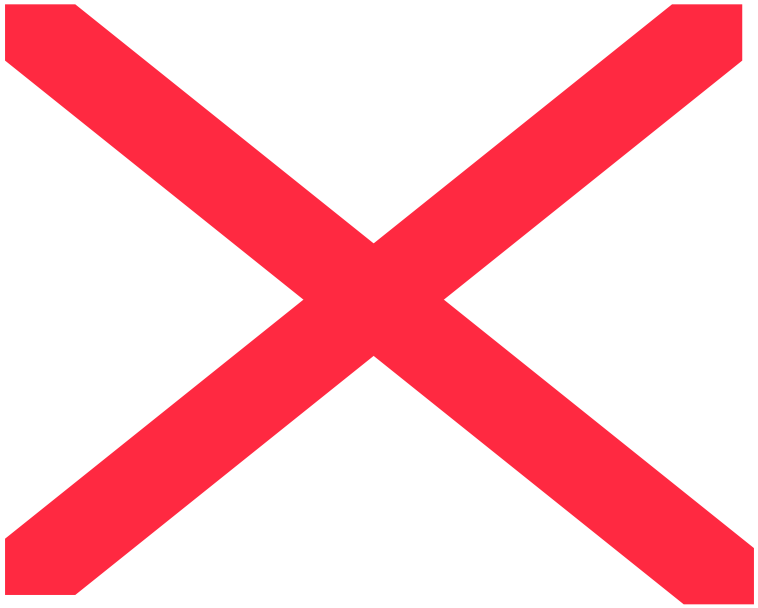


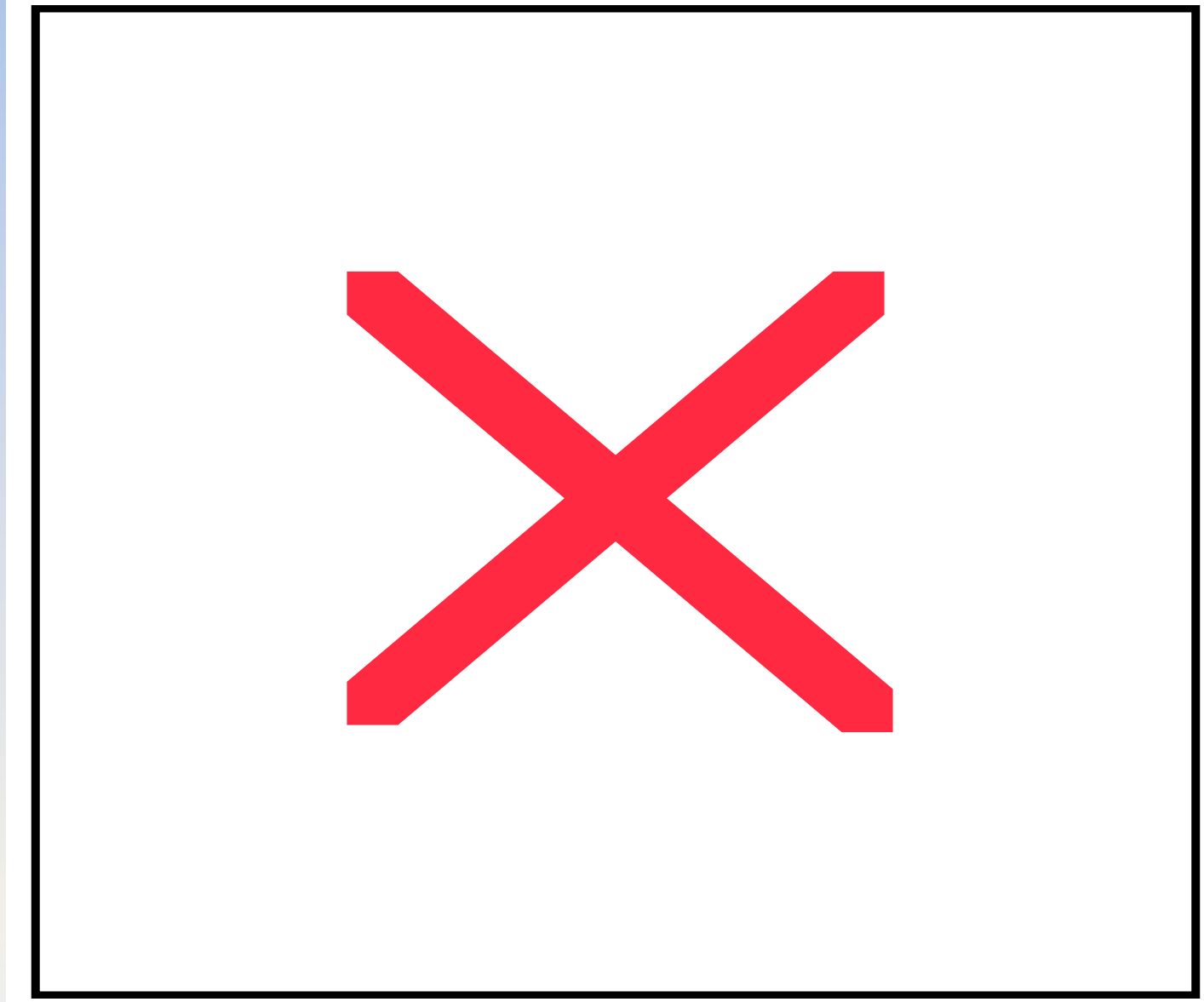
Maxwell Equations

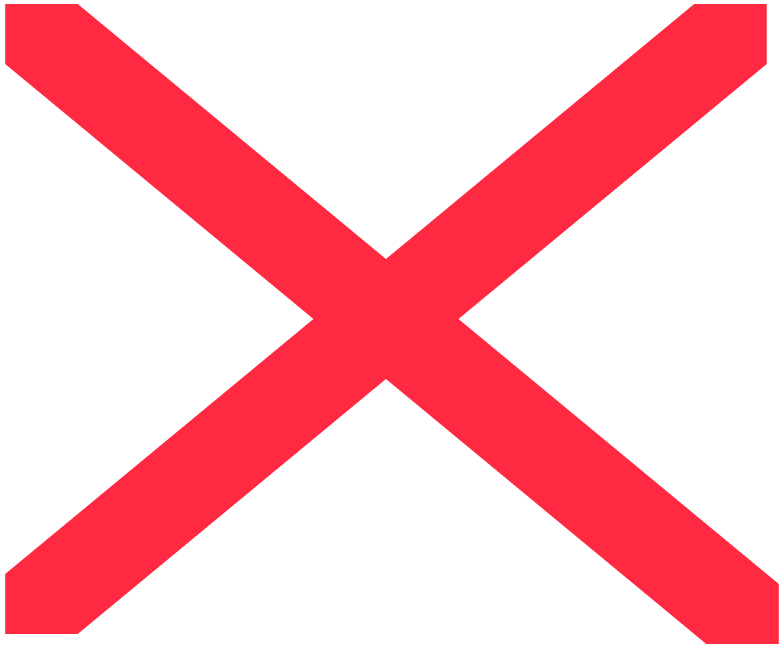




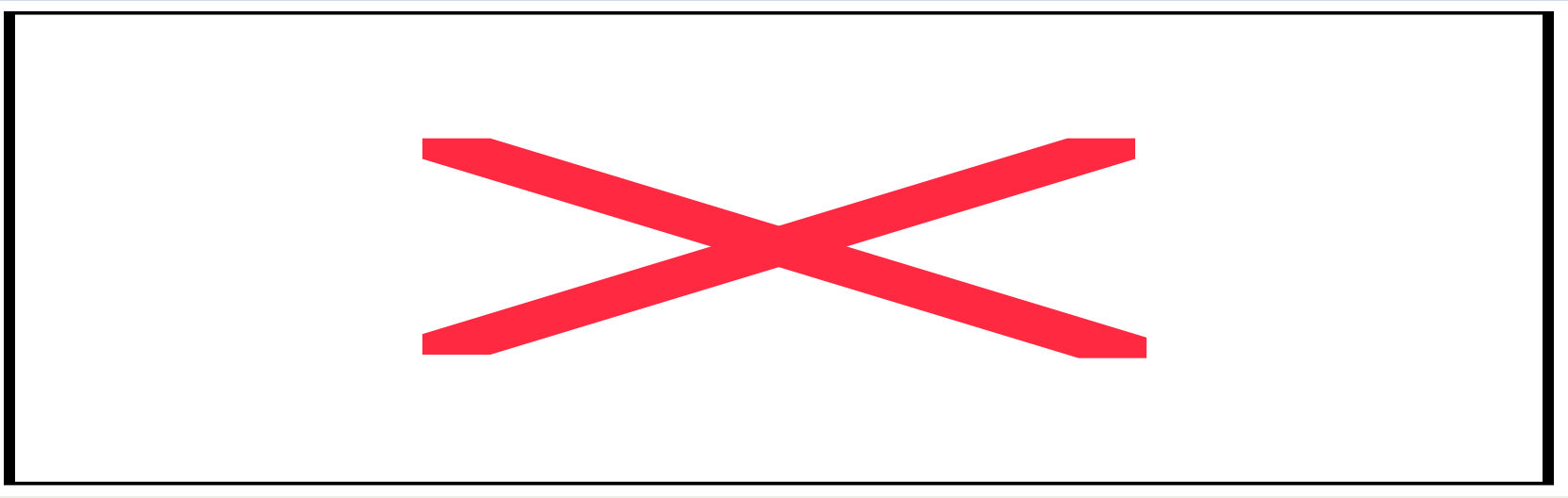




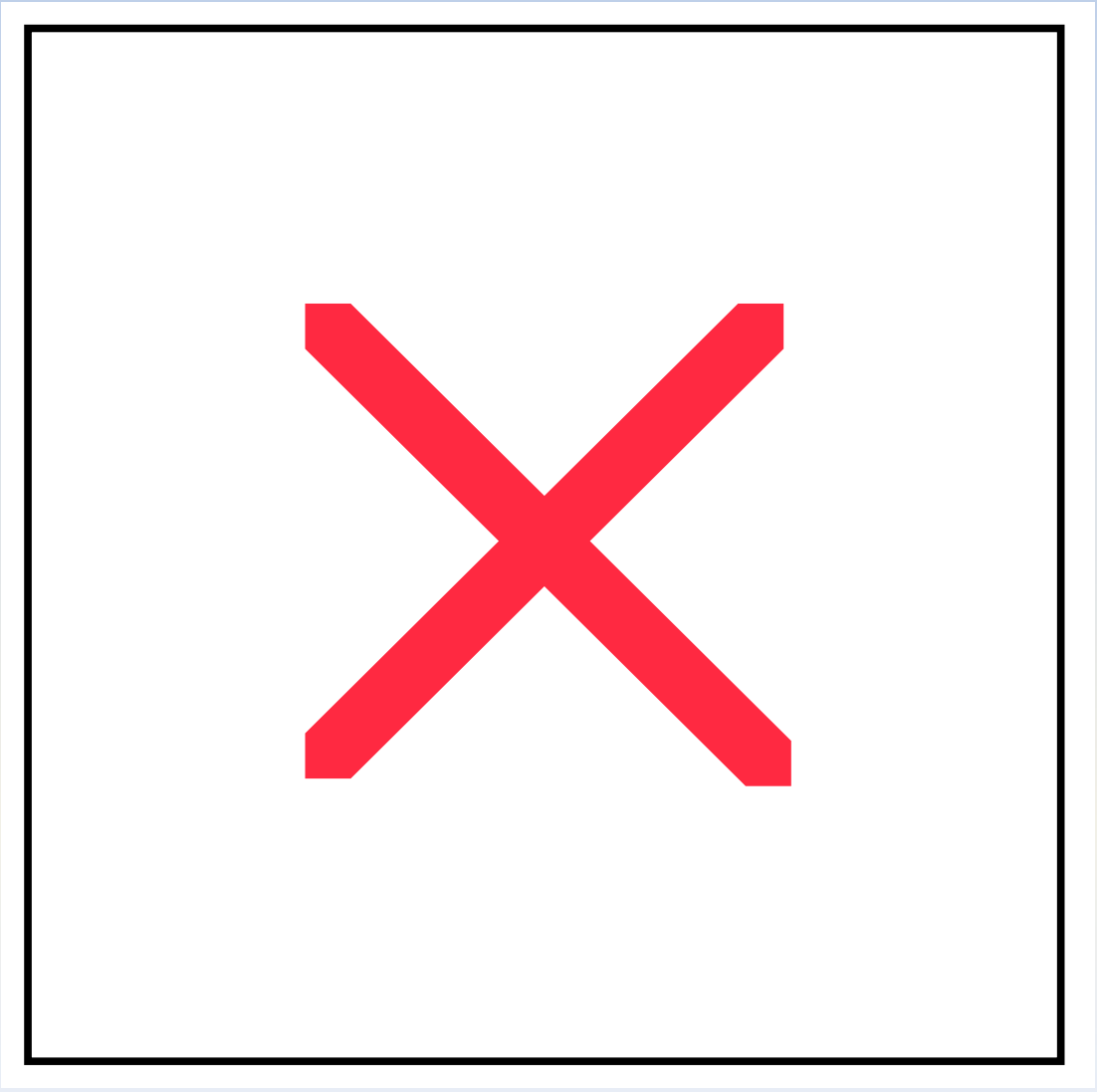




CONCLUSIONS



CONCLUSIONS



CONCLUSIONS