Vibrational Excitation induced by electron beam and cosmic rays in Gravitational Wave bars

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e-Print: **arXiv:1105.4724** [gr-qc]
in press on Nuclear Instruments and Methods in Physics Research

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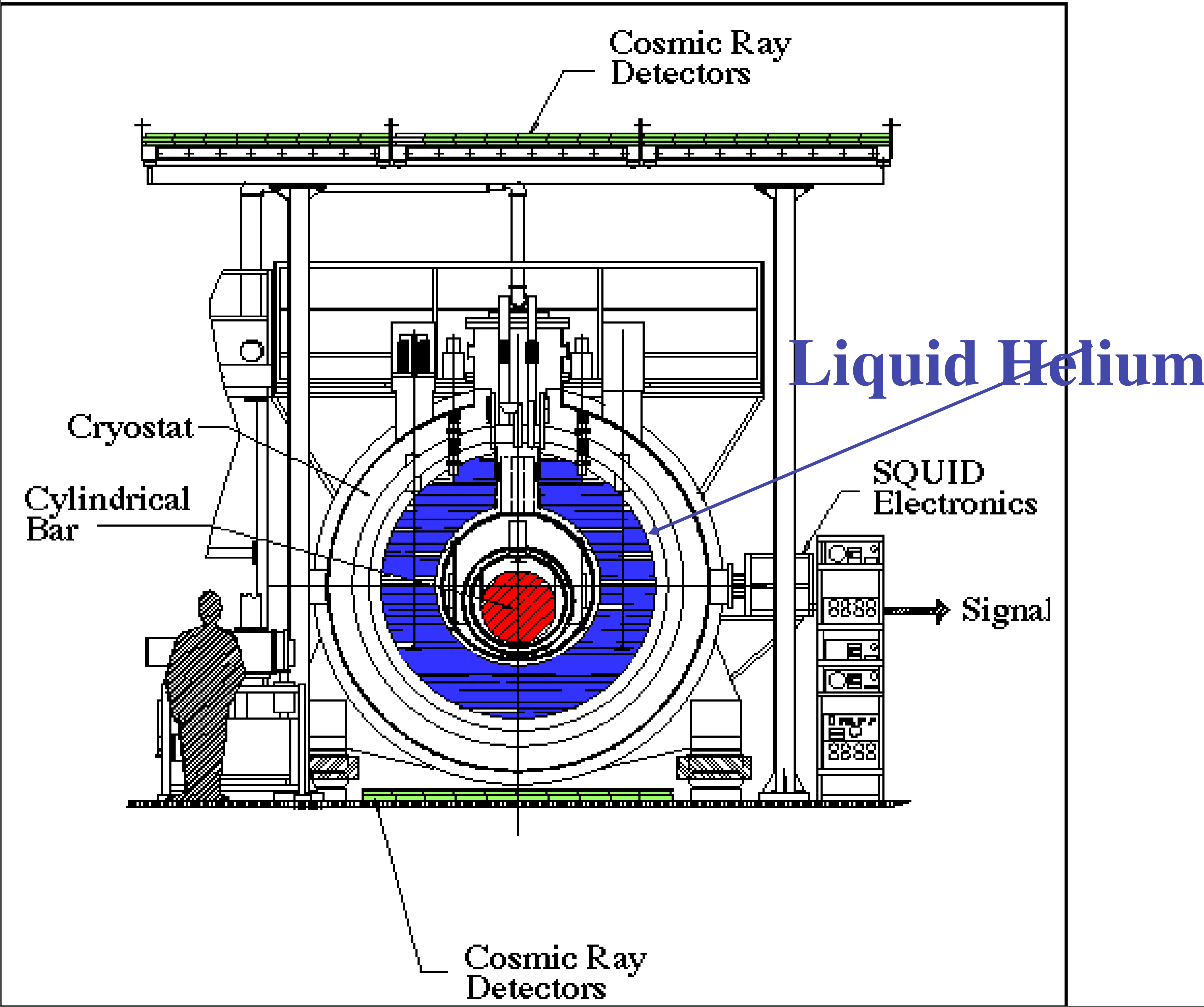
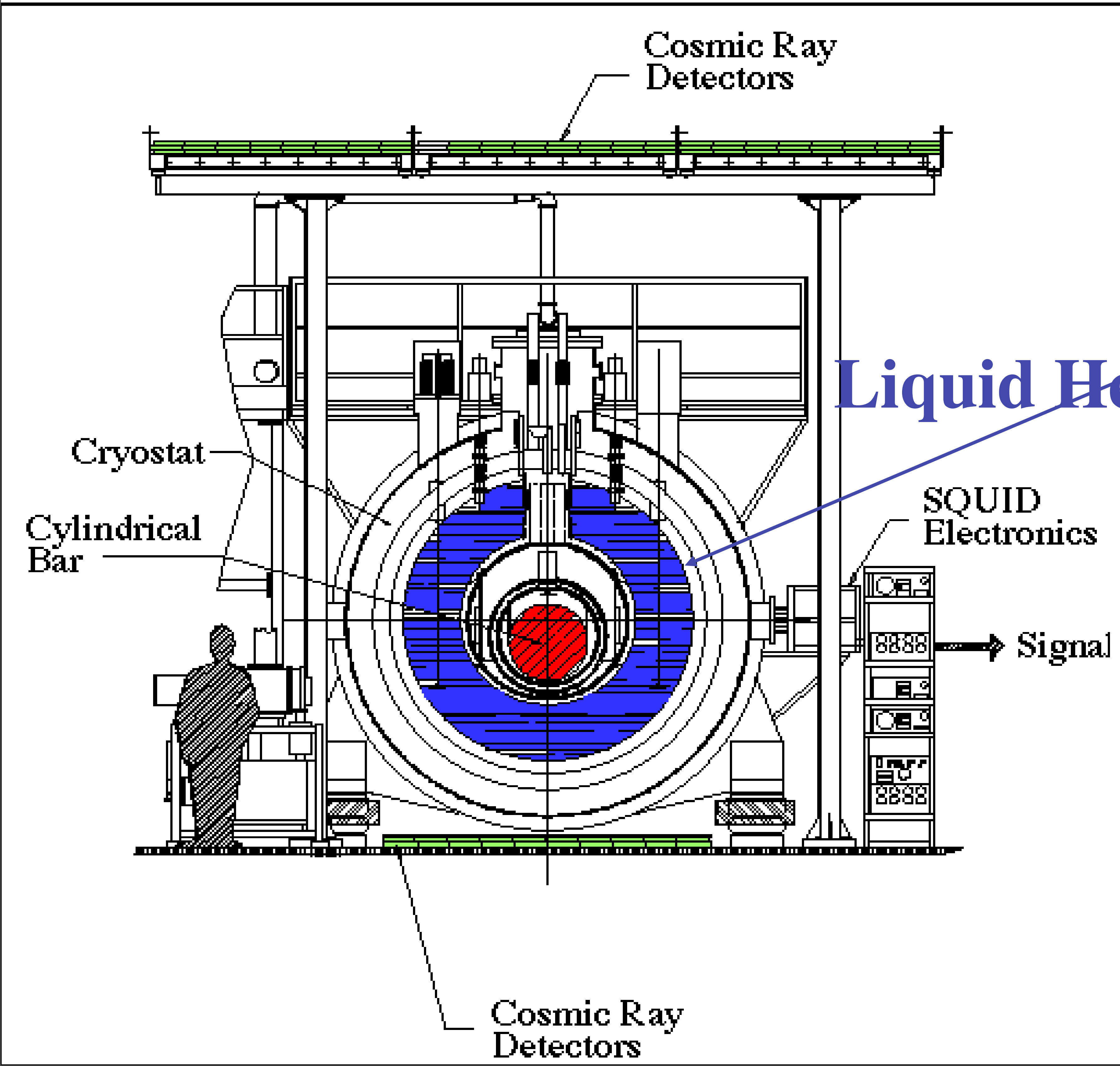
Nautilus (the first cooled at 100 mK in 1998)



Nautilus (the first cooled at 100 mK in 1998)

Al 2036 bar 2300 Kg L=3 m r=0.3m



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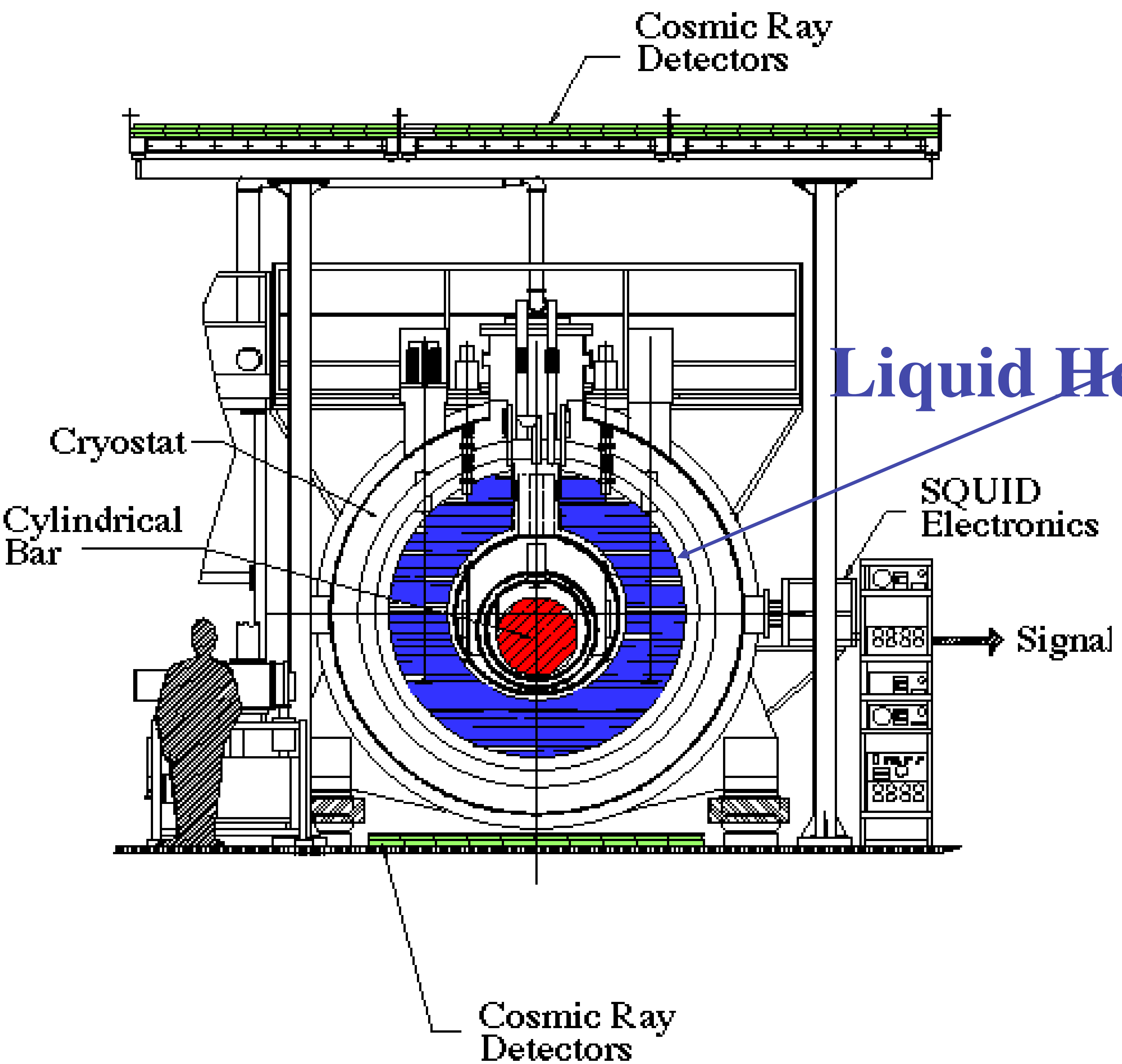
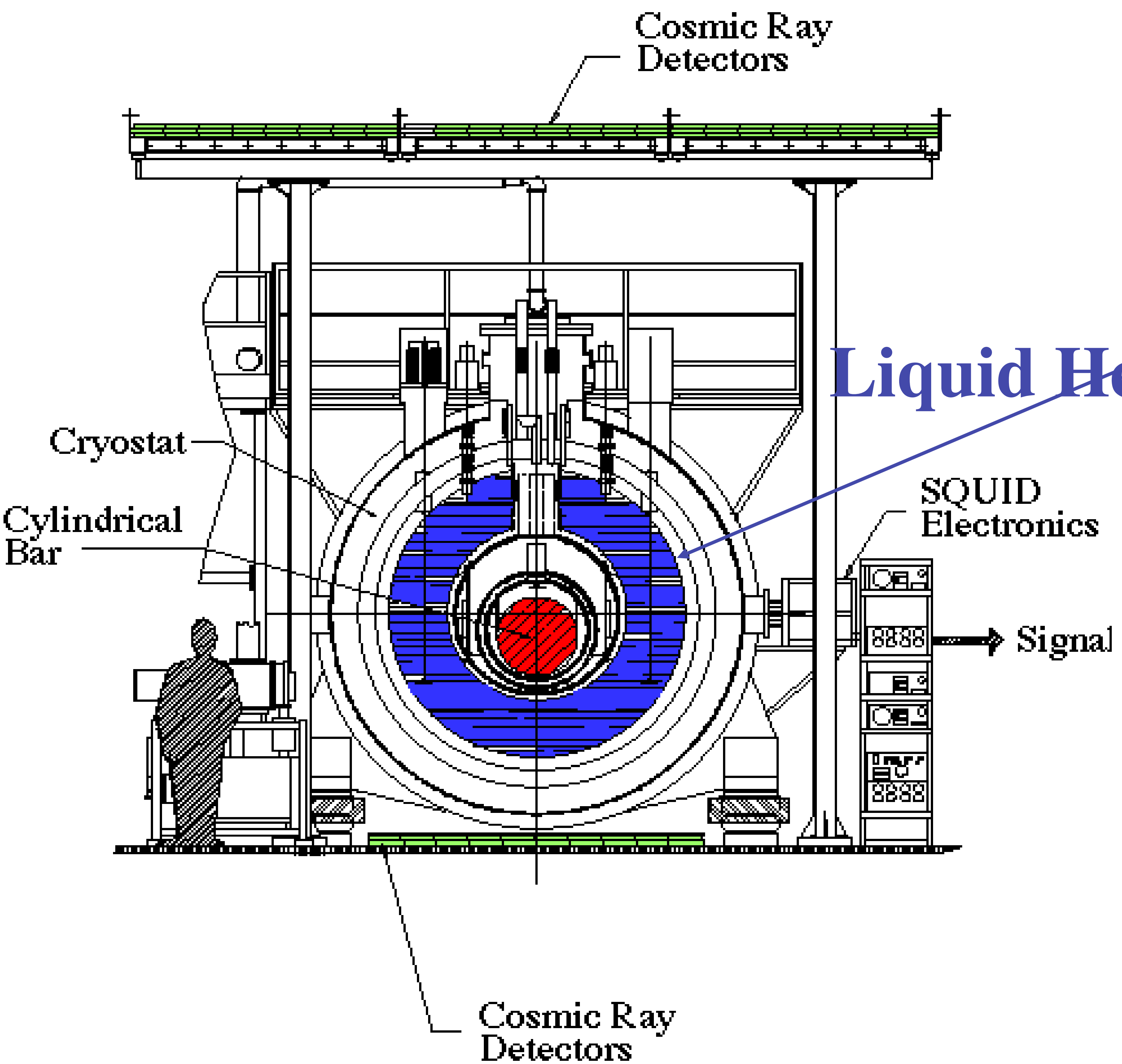


Al 2036 bar 2300

Cross section : 2 aluminum shields, container for helium **2000 liters**, dilution refrigerator with ^{3}He ^{4}He mixture

Nautilus (the first cooled at 100 mK in 1998)



Al 2036 bar 2300

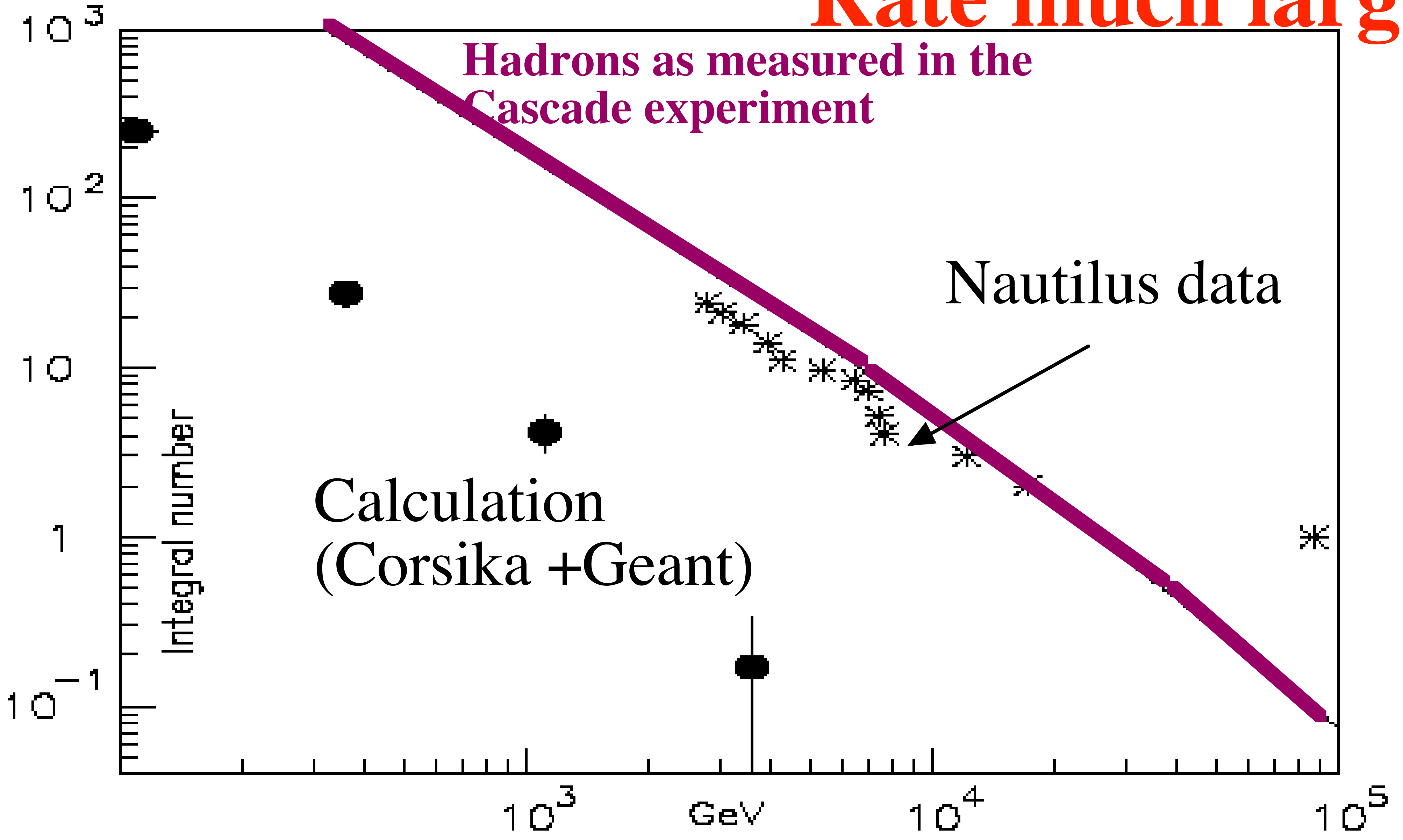
Cross section : 2 aluminum shields, container for helium **2000 liters**, dilution

Mechanical suspension: shields are suspended in a chains and copper wire around the bar 260 db @ 1 Khz

A big surprise in 1998!!!

(Nautilus first detection of cosmic rays in a GW detector)

Rate much larger !!

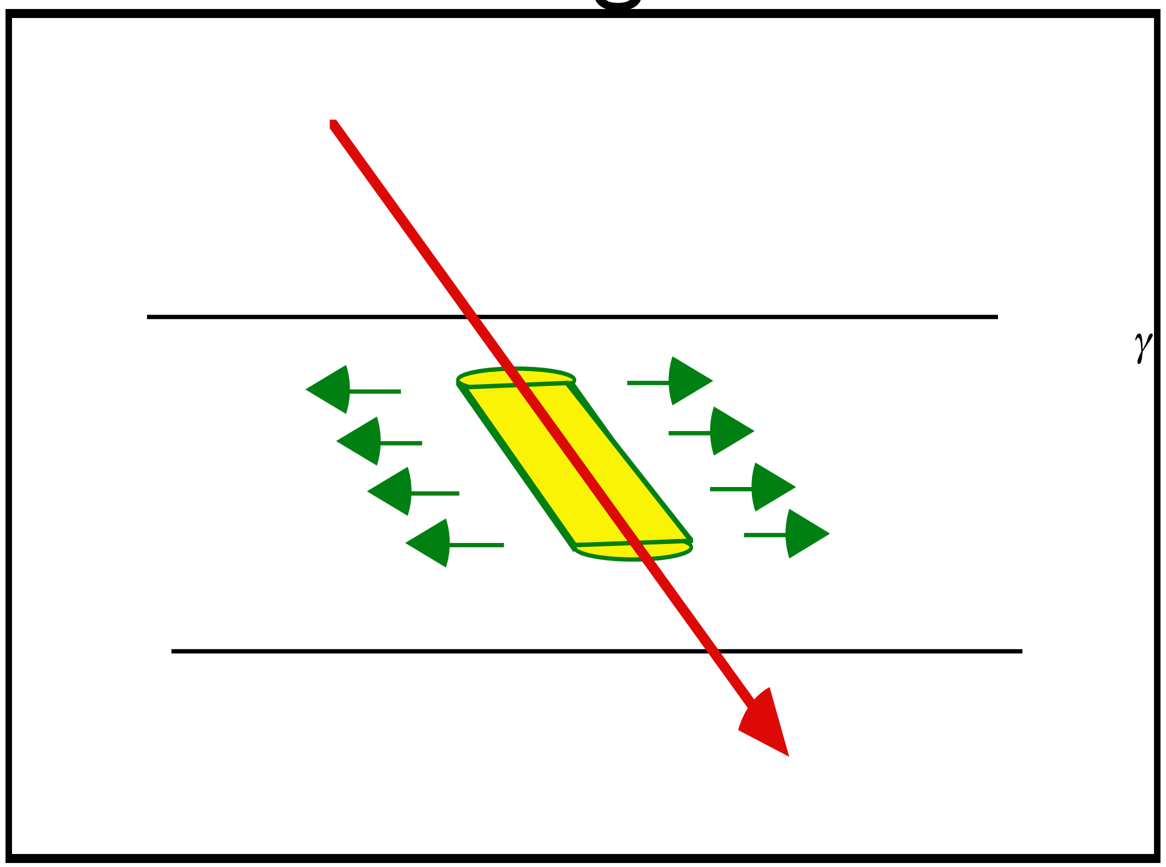


The hadrons measured by Cascade should be and upper limit, because

the bar should contain only ~a few percent of the hadronic energy

Interaction of a particle with a bar: Thermo-Acoustical model

Ionization energy lost is converted in thermal heating and therefore pressure wave



$$\delta T = \frac{\delta E}{\rho C V_0}$$

$$\delta p = \gamma \frac{\delta E}{V_0} \qquad \gamma = \frac{3\alpha}{\rho\, k C_v}$$

$$k = 3*(1-2*pois)/Y$$

γ Grunesein parameter

Y = Young module, C= specific heat, α linear thermal expansion coefficient

pois=Poisson module

Thermal acoustical conversion (General case for a single particle)

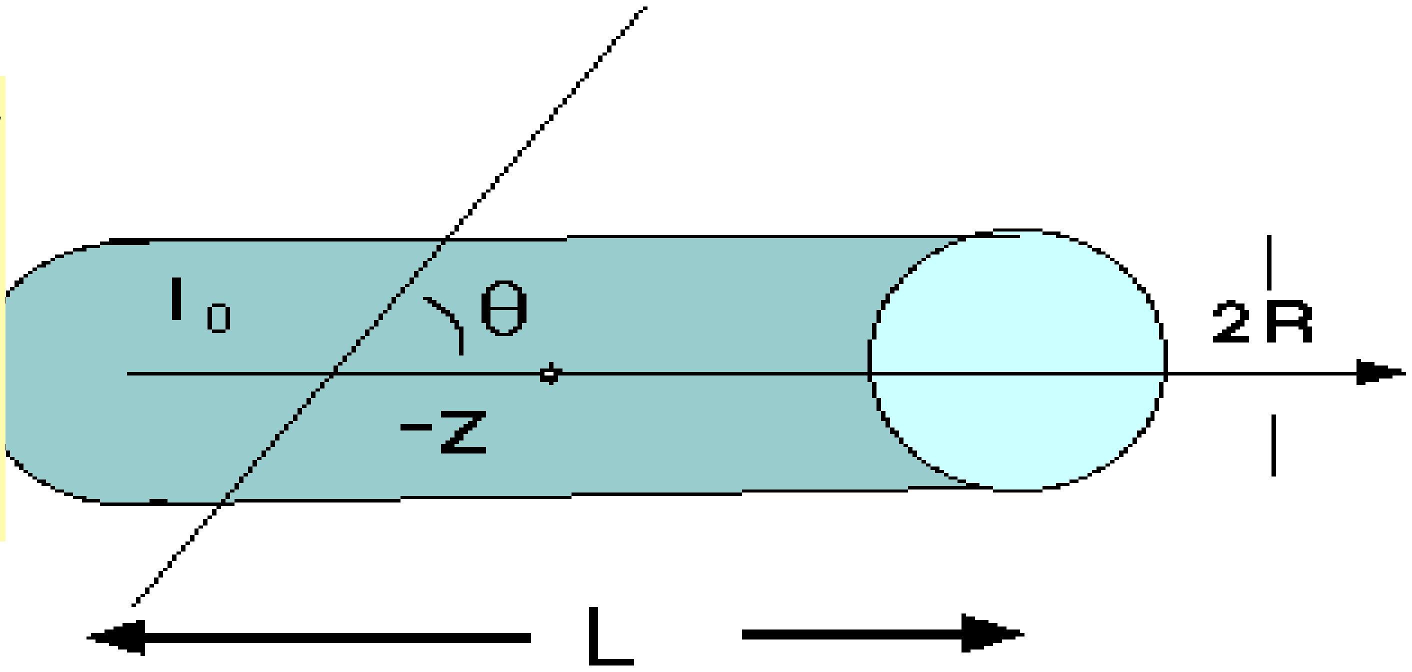
$$E_n = \frac{1}{2}\frac{l^2}{V}\frac{G_n^2}{\rho v^2}\gamma^2\left(\frac{dE}{dX}\right)^2$$

Allega A.M. & Cabibbo N. Lett Nuovo Cim 38 (1983) 263-
A. De Rujula & B. Lautrup, Nucl Phys. B242 (1984) 93-144

G_n cylinder form factor, first order in R/L

(Barish-Liu Phys Rev Lett 61 1988)

$$T_{eff} = 2.75 * 10^{-9}\left(\frac{dE}{dX}\right)^2\left(\sin\left(\frac{\pi z}{L}\right)\frac{\sin\left(\frac{\pi l_0 \cos\theta}{2L}\right)}{\frac{\pi R\cos\theta}{L}}\right)^2$$



The thermo-acoustical model in a superconductive state

- in addition to the expansion due to the heating we could have a release of additional energy if a local transition from the superconductive (***s***) state to a normal (***n***) state occur, due to the different energies of the ***s*** and ***n*** state. This effect has been demonstrated in the "superconductive strip" detector

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so two possibilities:

1) no local ***s - n*** transition : normal thermo-acoustical model with low temperature parameters

2) ***s - n*** transition : overlapping of two effects :

thermo-acoustical with normal state parameters + ***s - n*** transition pressure wave

the two effects could have different sign (“interference”)

$$\frac{X}{W} = \left[\left(\frac{X}{W}\right)_{trans}\right] + \left[\left(\frac{X}{W}\right)_{norm}\right] =$$

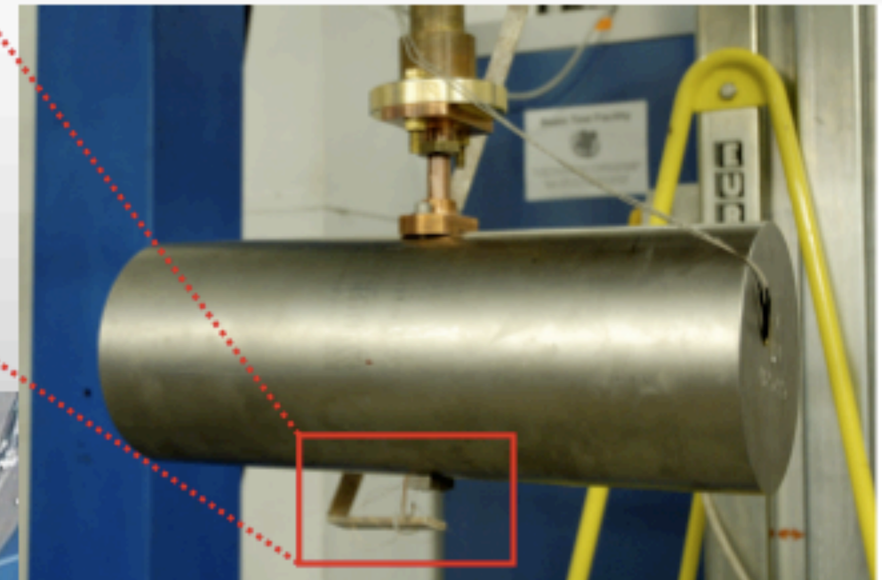
$$\left[\mathcal{F}\left(H_c, \frac{\partial H_c}{\partial T}, \frac{\partial H_c}{\partial P}\right)\right] + \left[B\left(\frac{\alpha}{c_V}\right)_{norm}\right]$$

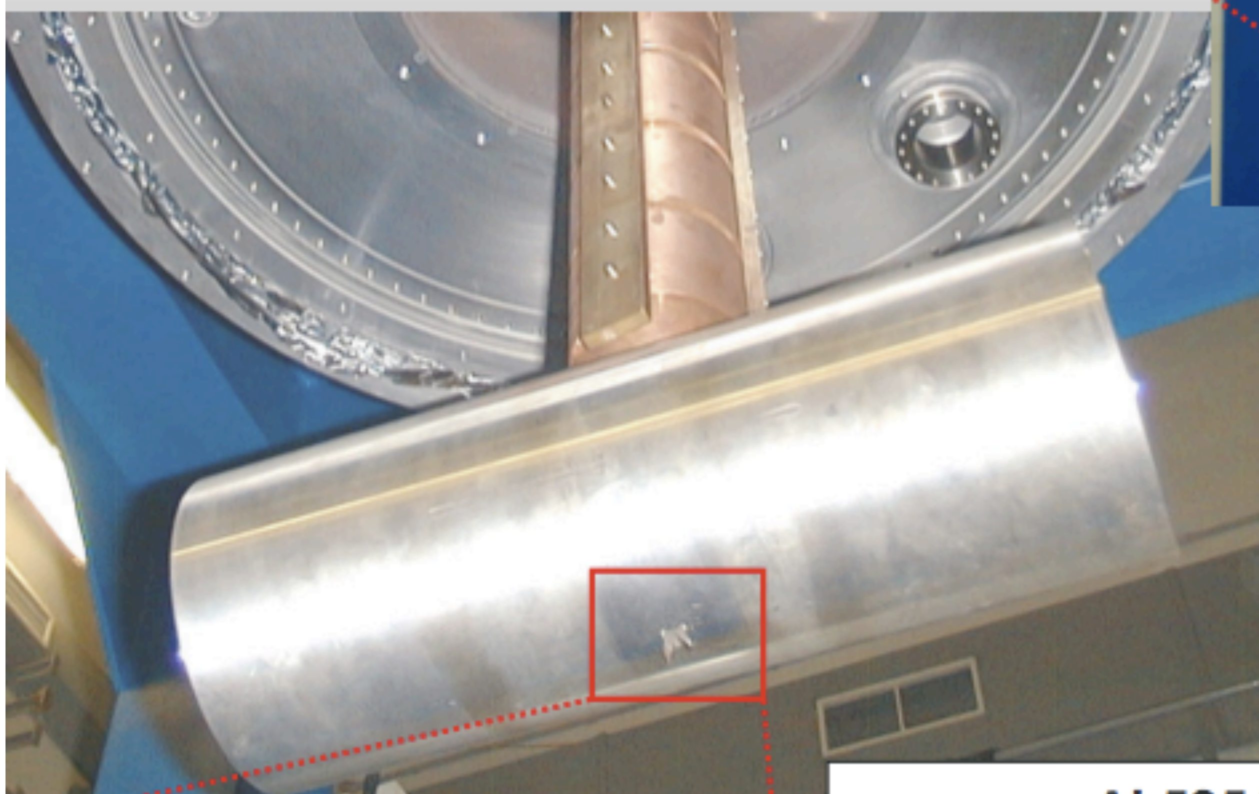
X amplitude W energy

Very difficult to have a reliable prediction

Experimental Setup

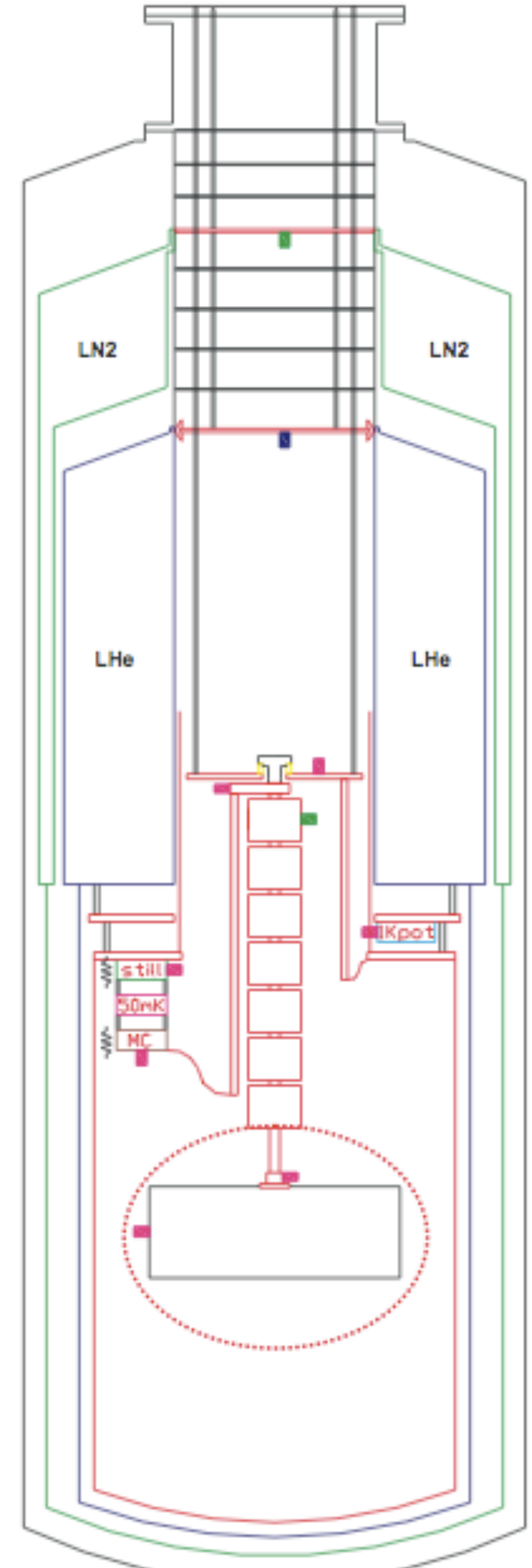
Rivelazione Acustica di Particelle





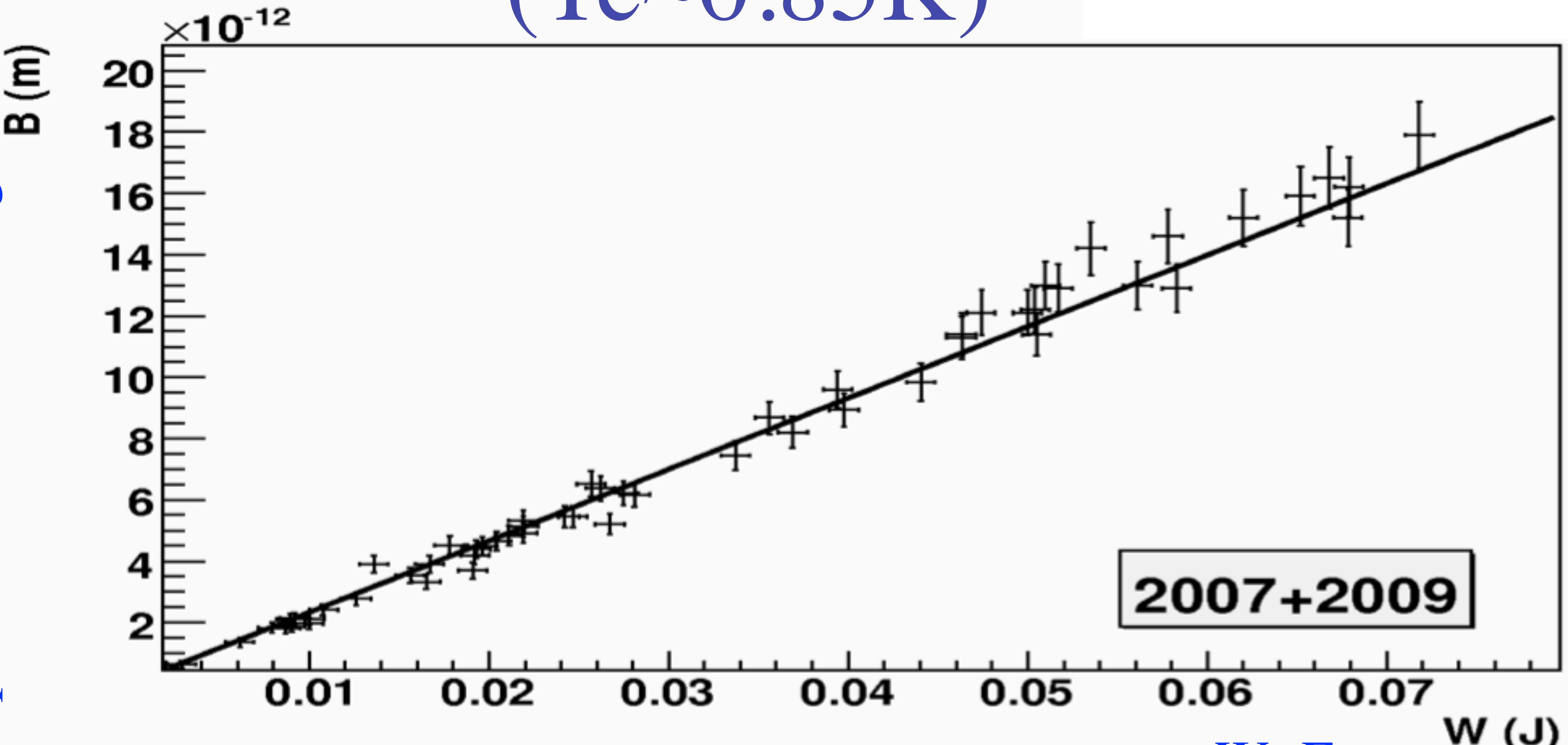
Niobium Bar
- 27.4x10 cm, 18.4 kg
- ν = 6373 Hz @ 290 K
- annealed, purity > 99%
- 2 PZ24 ceramics in parallel glued to the bottom center
- $\lambda \sim 10^6$ V/m

Al 5056 Bar
- 50x18.1 cm, 34.1 kg
- ν = 5096 Hz @ 296 K
- 2 Pz24 ceramics in parallel embedded in the bar
- $\lambda \sim 10^7$ V/m



Typical RAP results for 0.9< T <2K (Tc~0.85K)

B=Amplitude of the first longitudinal mode

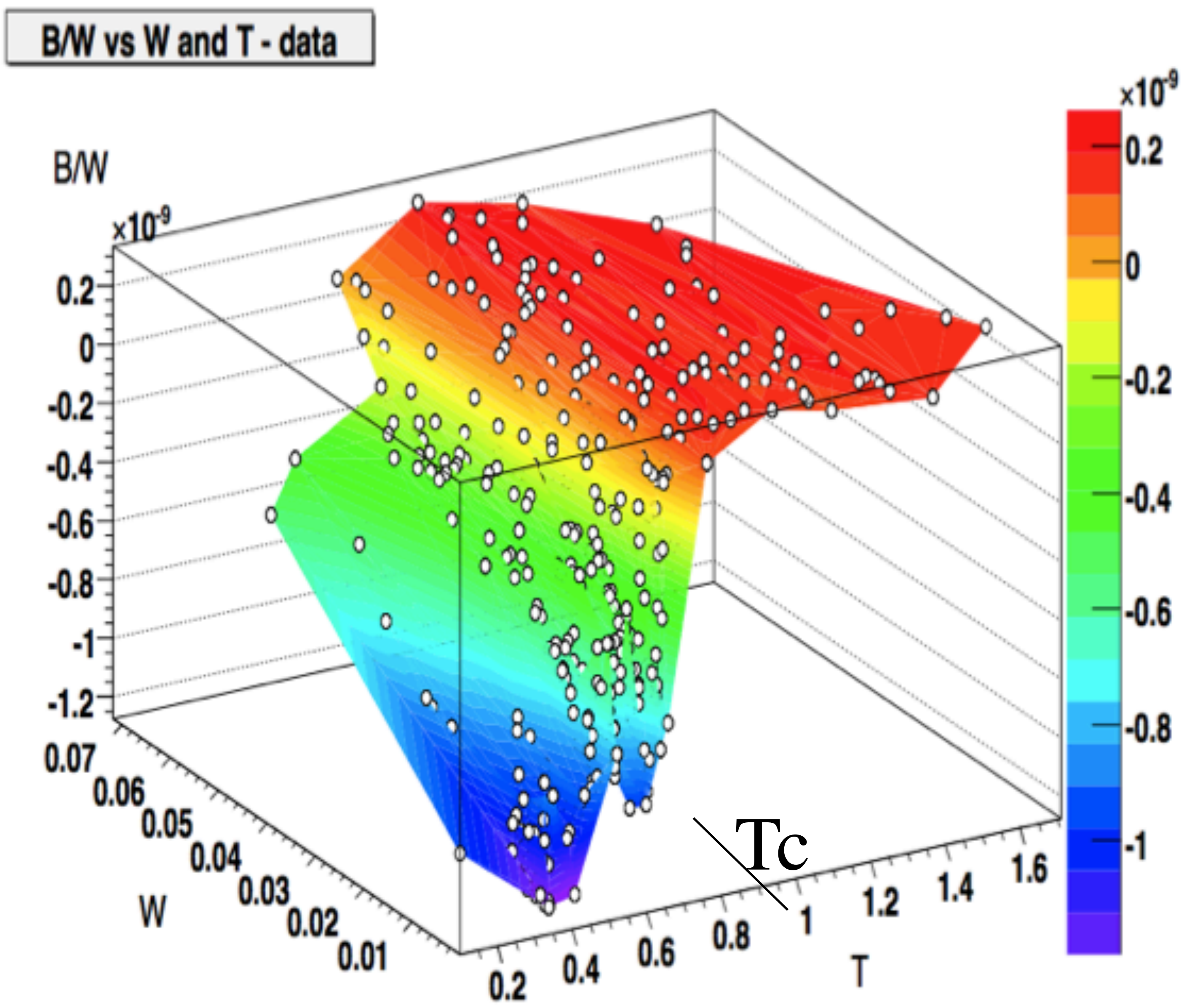


W=Energy

Amplitude B of the first longitudinal mode proportional to W the energy delivered in the bar

B/W=constant

RAP results for T< critical temperature



- B/W not constant for T<TC

the sign of B/W becomes negative for T<TC==>> initial compression of the bar

apparently complicated behavior

Figure 9: *Synoptic view of the data for temperature $T \leq 1.6$ K, the transition temperature is about 0.9 K. The plot shows the measured B/W (with sign) vs temperature T and deposited energy W. The most relevant feature of this plot are: a constant value of B/W for $T \geq T_c$, the change of sign of B/W for $T \leq T_c$ and the dependence on W of B/W for $T \leq T_c$. The experimental data are the open circles. The shadowed regions are interpolations of the data. The point at the lowest temperature $T = 0.14$ K is obtained from the cosmic ray NAUTILUS data.*

RAP results for T< critical temperature

RAP results for T< critical temperature

- the non linearity for T<Tc and the complicated behavior is due to saturation effects. A typical electron produces a transition in a cylinder of 1μ radius. With an electron beam having 10^9 particles the cross section switched to normal is 30 cm^2 larger than the beam cross section (20 cm^2)
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$$\frac{B}{W} = a + (b(T) - a)\exp\left(\frac{-W}{p_0\ \rho\ C_I(T)}\right)$$

$$b(T) = p_1 + p_2 T + p_3 T^2$$

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  - a~2.25×10–10 mJ–1 is the constant value of B/W forT >Tc and b (T) the value of B/W for T <Tc and W →0
  - C_I is the integrated specific heat between T and the critical temperature
  - 4 free parameters p

RAP results for T< critical temperature

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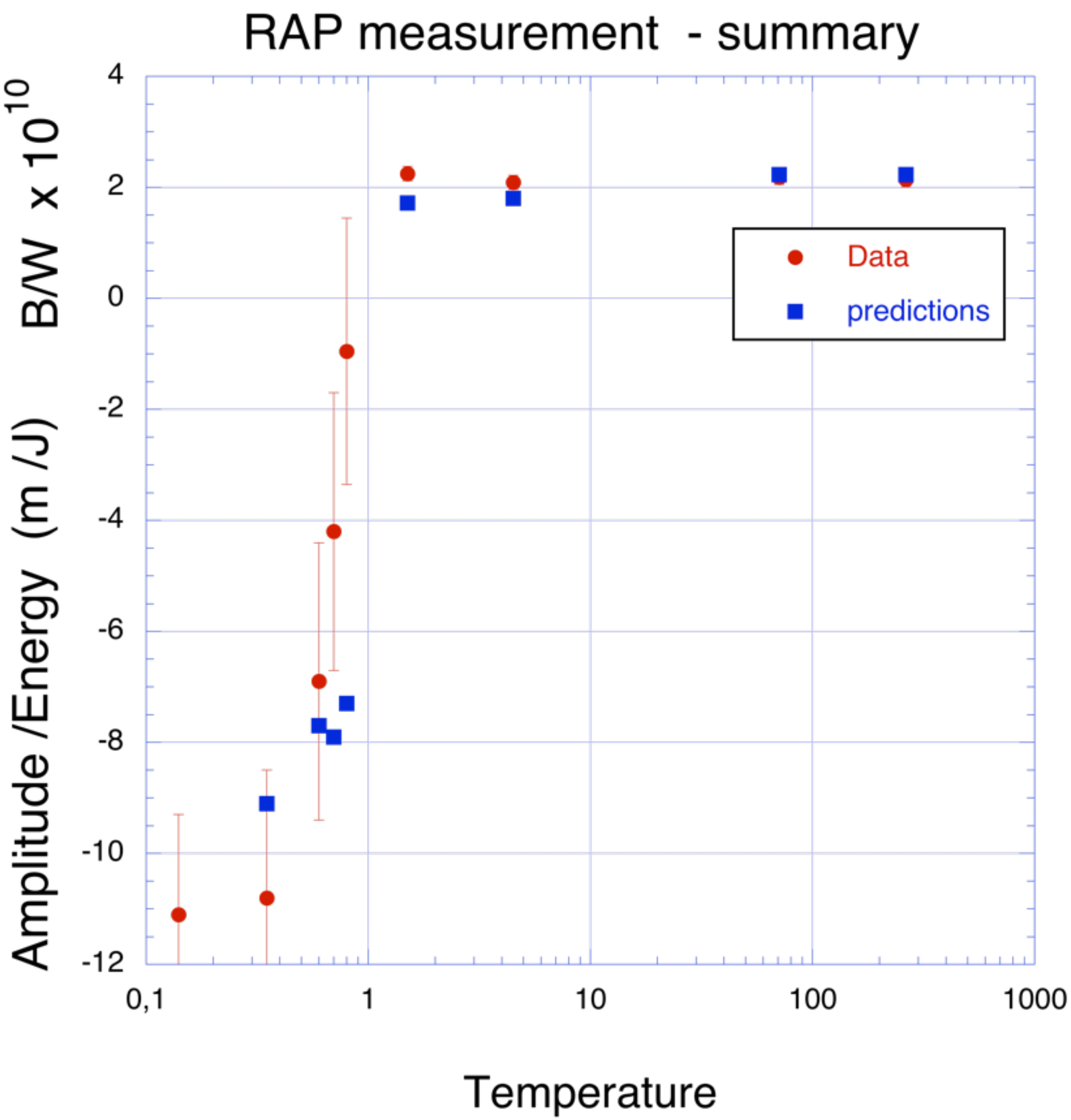
Fit result $\chi2$/d.o.f. = 368/286 = 1.29

- the model of De Rujula Cabibbo et al. with the of two effects when T<Tc is correct. But only for small value of the energy (as in the case of cosmic rays).
- The fit can be used to find B/W when W->0
- measurements necessary due the approximations in the model and to the poor knowledge of low temperature parameter

Summary of the RAP measurements

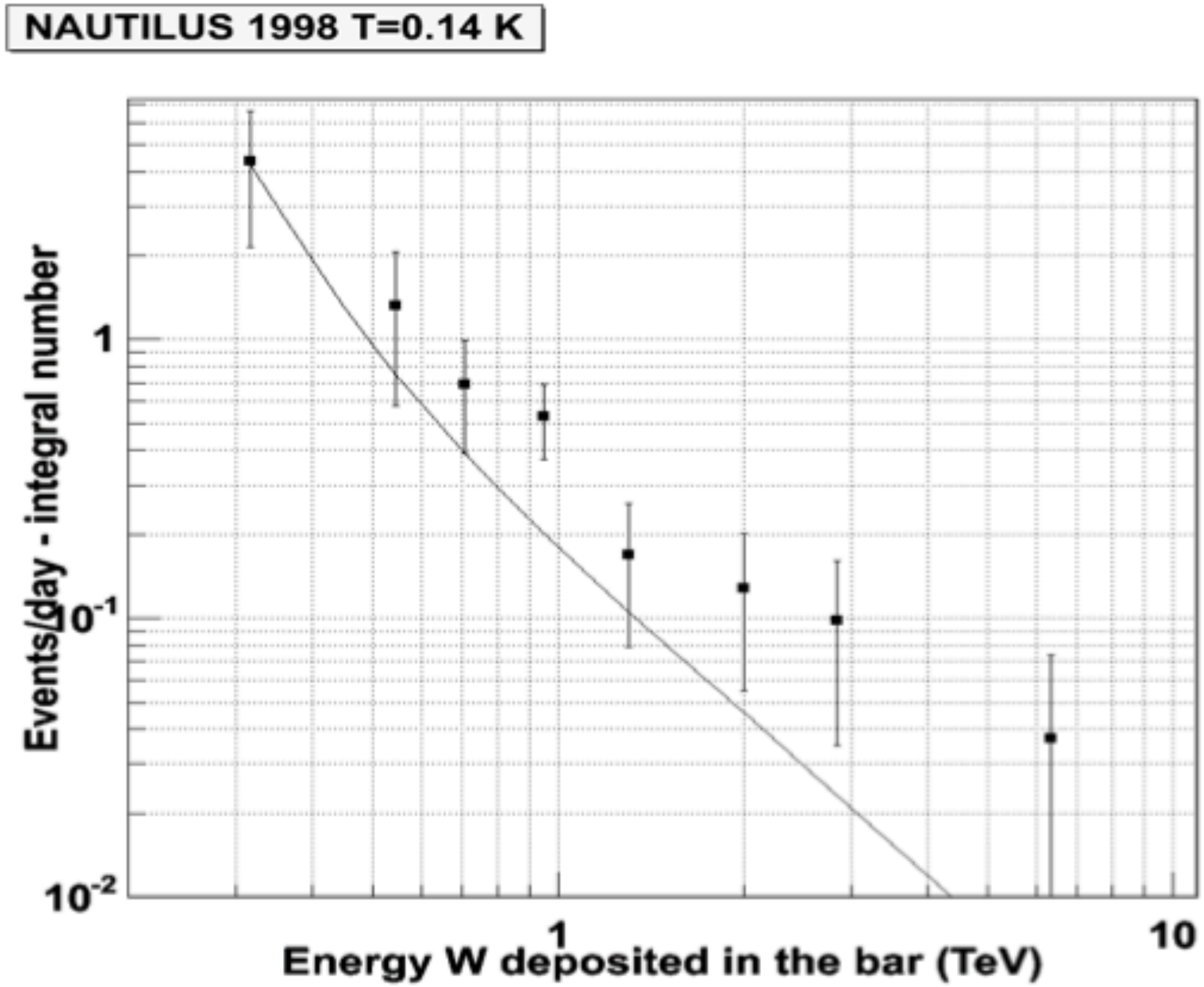


The value at T<Tc are obtained from the fit for W (Energy)->0

Small disagreement also for T 1-4 K

Enhancement of ~ 4.9 for T ~0.1-0.2 K

Nautilus data at T=0.14 K and predictions using the RAP 4.9 enhancement



Agreement : No exotics!

Figure 13: *NAUTILUS 1998, at T = 0.14 K. The integral distribution of the event rate after the background unfolding, compared with the expected distribution (continuous line). The prediction is computed using the data of Table 4 and using the value $\delta_s = 5.7$ measured by RAP. The good agreement suggests the absence of anomalous components of cosmic rays or anomalous interactions of cosmic rays with a superconductive bar. Modified from Ref. [34].*

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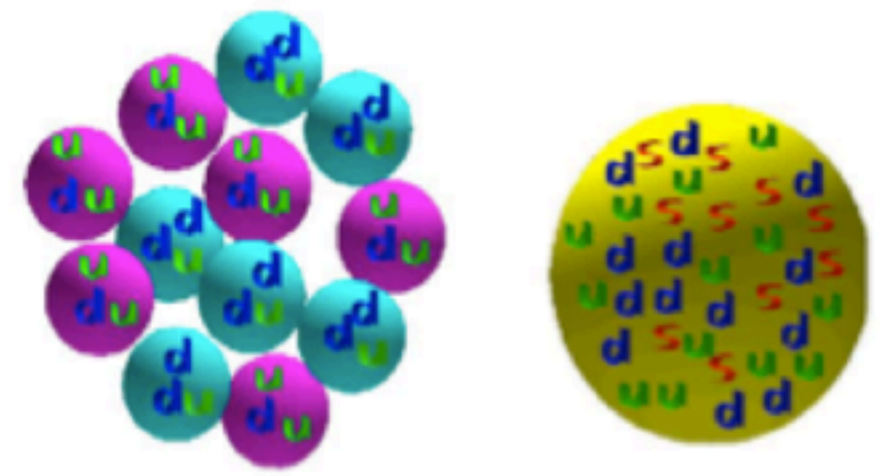
- **Application to exotic** particle searches (nuclearites..)
- Cosmic rays can be also **a noise in GW interferometers** (mirrors). Two mechanism : one similar to the bar, the other produces a pendulum oscillation. Not a problem for the next generation advanced detector, but the calculation for muons of Yamamoto et al., Phys. Rev. D 78 (2008) should be extended to include E.M. and hadronic showers.

Additional slides

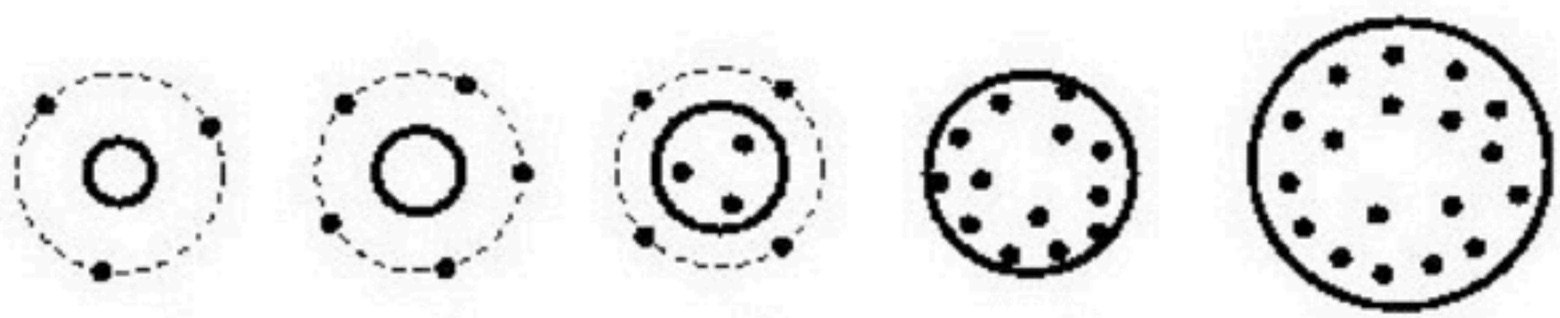
Strange Quark Matter (nuclearites, strangelets)

E. Witten, Phys. Rev. D30 (1984) 272A. De Rujula, L. Glashow, Nature 312 (1984) 734

- Aggregates of u, d, s quarks + electrons of ~ equal number, density: 3.5×10^{14} g cm^{-3}.
- Ground state of nuclear matter (E/A < 930 MeV).
- Stable for any baryon number A (few < A< 10^{57}).



..a qualitative picture…



- ➤ Nuclearites : core + electrons , neutral, A > 10^6 — CDM candidate
- ➤ Strangelets : positively charged, A < 10^6 — Cosmic ray component

Application: nuclearites searches in anti- coincidenc with the CR detector

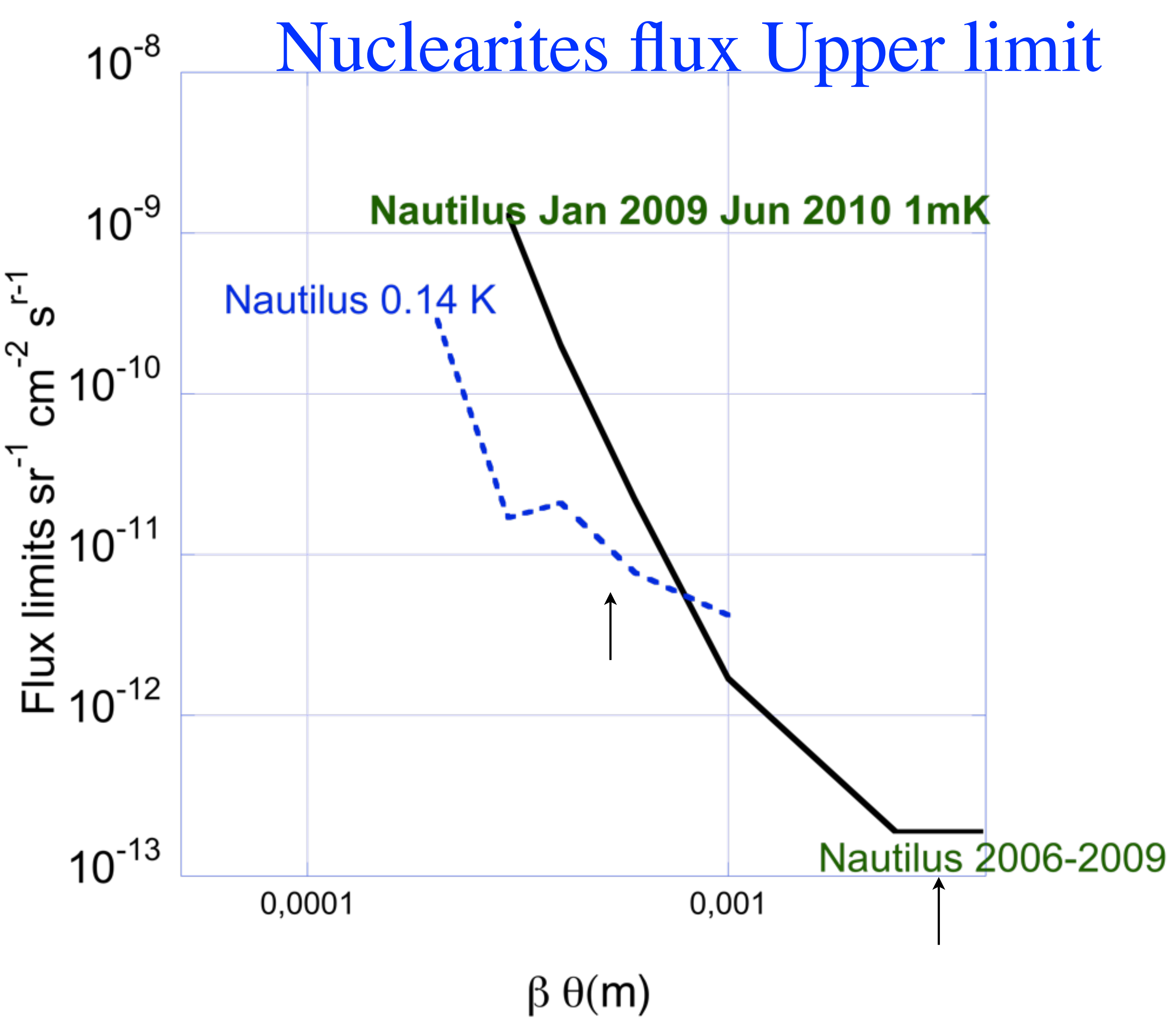
$$\frac{dE}{dx} = 480\frac{\text{GeV}}{\text{cm}}\left[\frac{\beta\theta(m)}{10^{-3}}\right]^2 ,$$

where the mass dependence is

$$\theta(m) = 1 \quad \text{if } m \le 1.5 \text{ ng} ,$$

$$\theta(m) = \left[\frac{m}{1.5 \text{ ng}}\right]^{1/3} \quad \text{if } m \ge 1.5 \text{ ng} .$$

multiply by 2 if m <0.1 gr and $\beta=10^{-3}$



Previous results (Explorer) Ph Rev 47 1992

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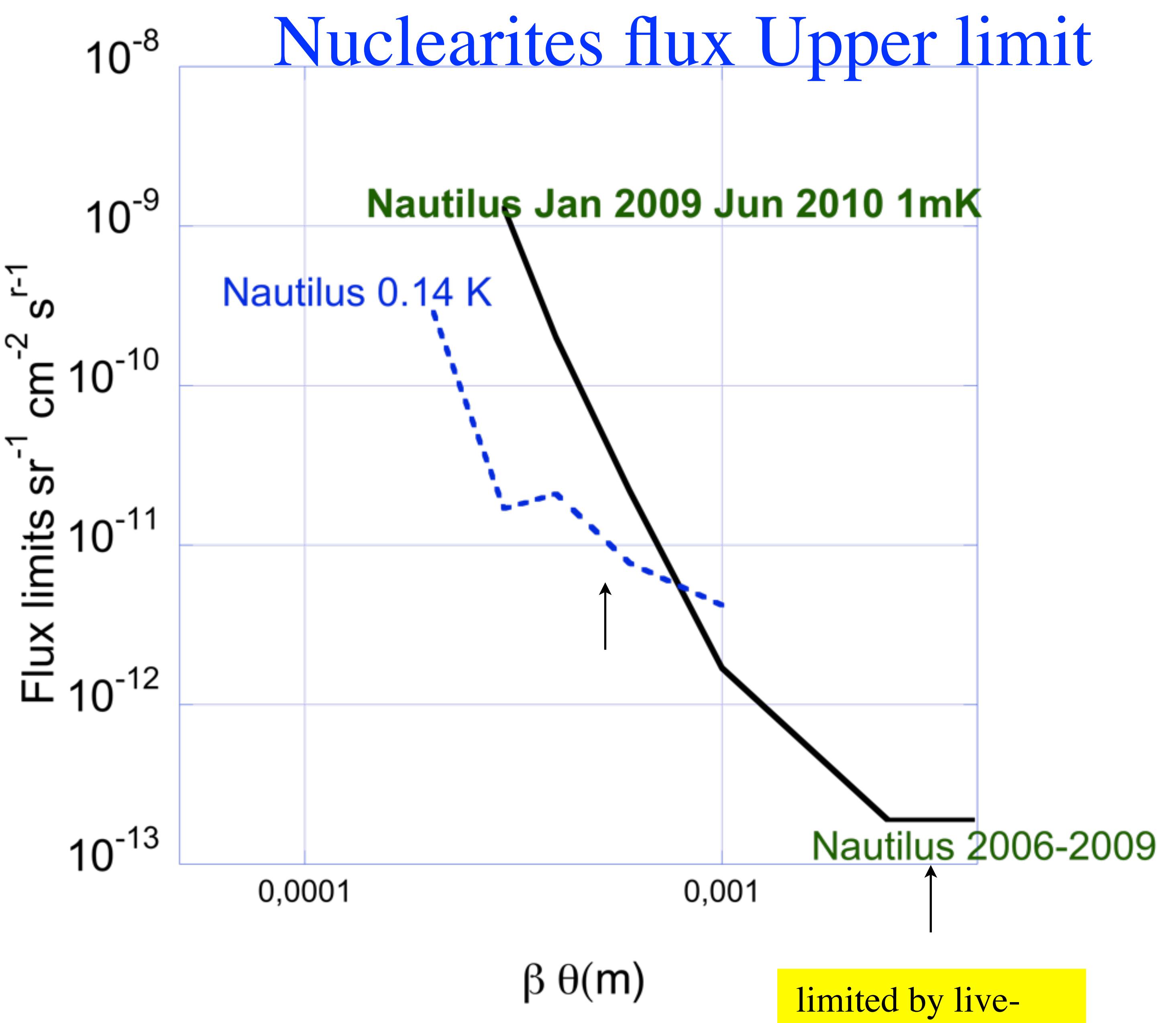

limited by live-time

Previous results (Explorer) Ph Rev 47 1992

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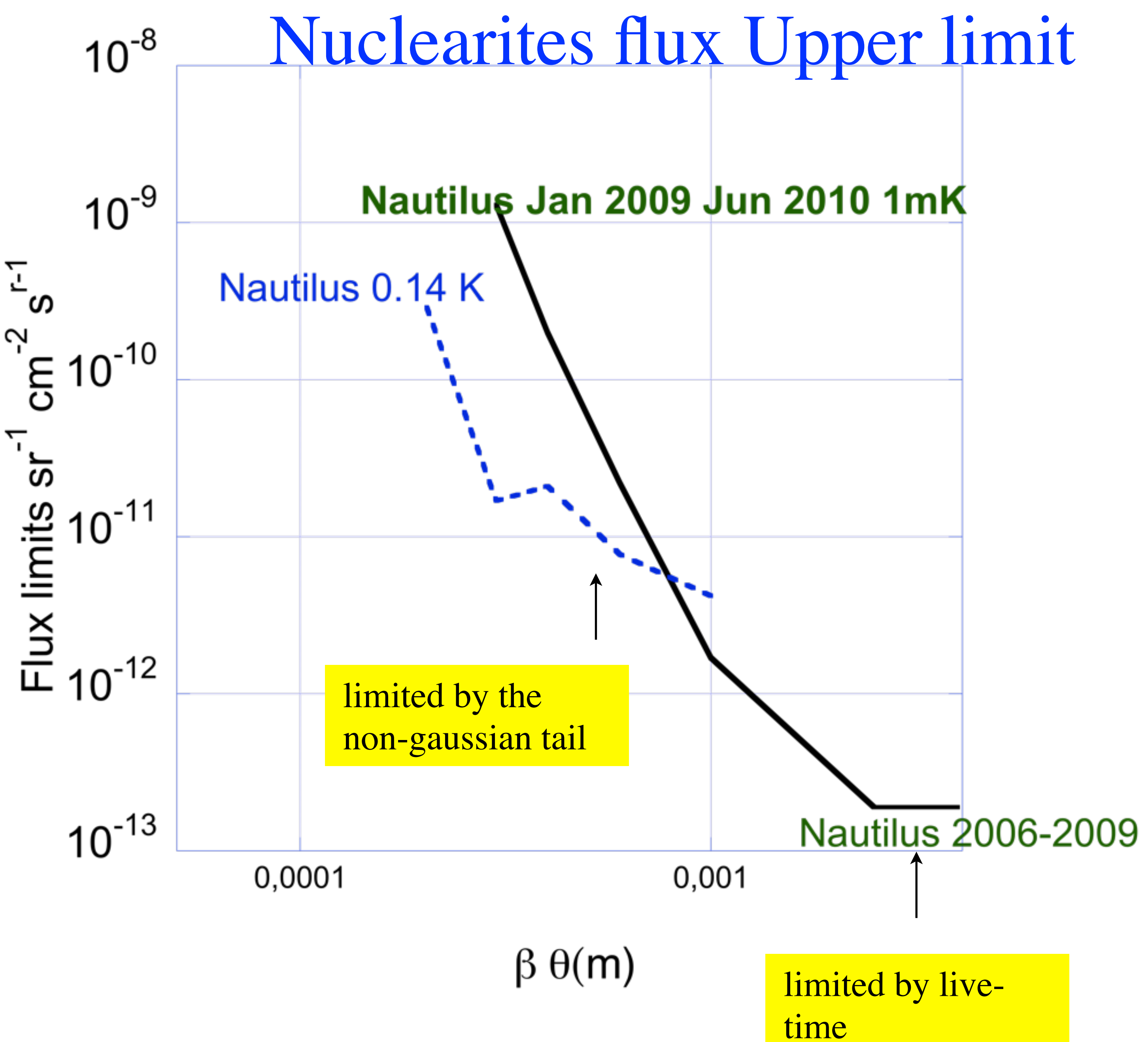

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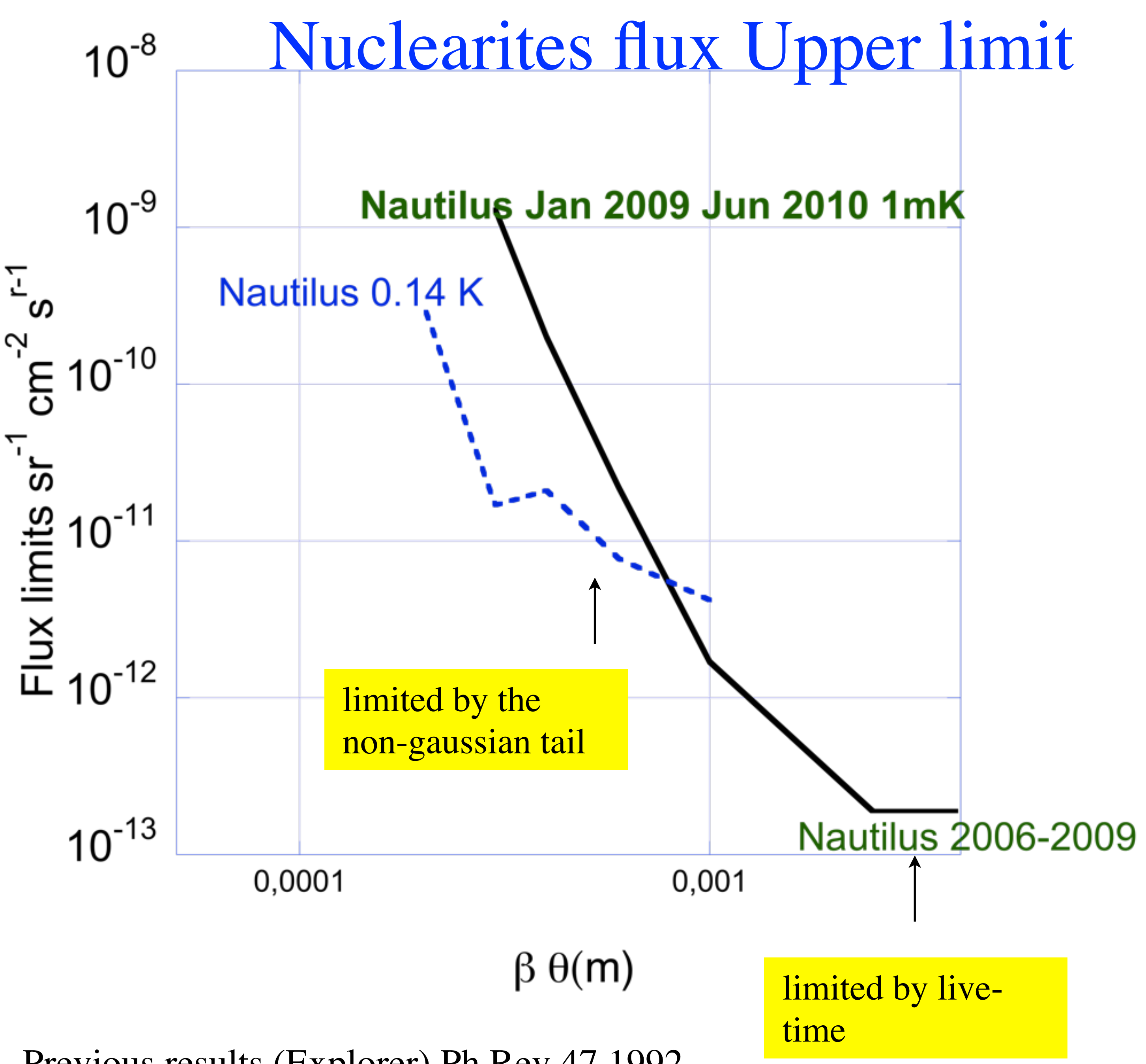
- limits are much higher than the one in other experiments (SLIM 1.4 10^{-15} MACRO 3 10^{-16})
- but some interest because the detection mechanism is quite simple, no threshold in β "calorimetric measurement"
- **for some masses limits < than DM matter limit**

multiply by 2 if m <0.1 gr and $\beta=10^{-3}$

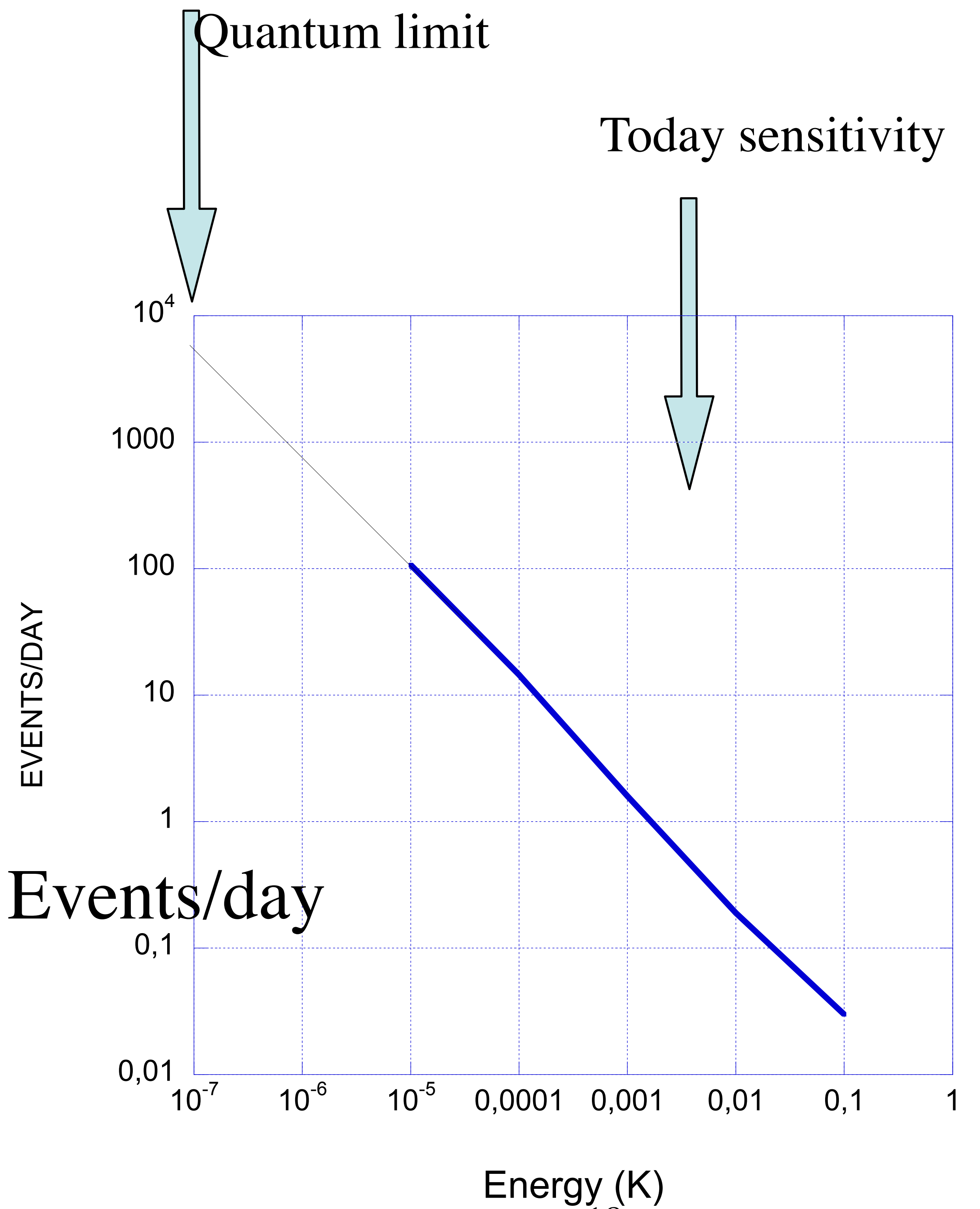


Previous results (Explorer) Ph Rev 47 1992

Cosmic rays rates in the bar - computed

Vibrational Energy E (K)	Deposited Energy W (GeV)	Muons	Ext Air Showers	Hadrons	Total (events/day)
$\geq 10^{-5}$	≥ 44.5	15.7	62	29.2	107
$\geq 10^{-4}$	≥ 141	1.6	8.9	4	14.5
$\geq 10^{-3}$	≥ 445	0.2	1	0.4	1.6
$\geq 10^{-2}$	≥ 1410	0.003	0.13	0.06	0.19
$\geq 10^{-1}$	≥ 4450				0.03

Table 1



With the today bar sensitivity events are due mainly to cosmic rays with a primary of energy >**~10^{14} eV**

Application antenna monitoring and performances study: time resolution

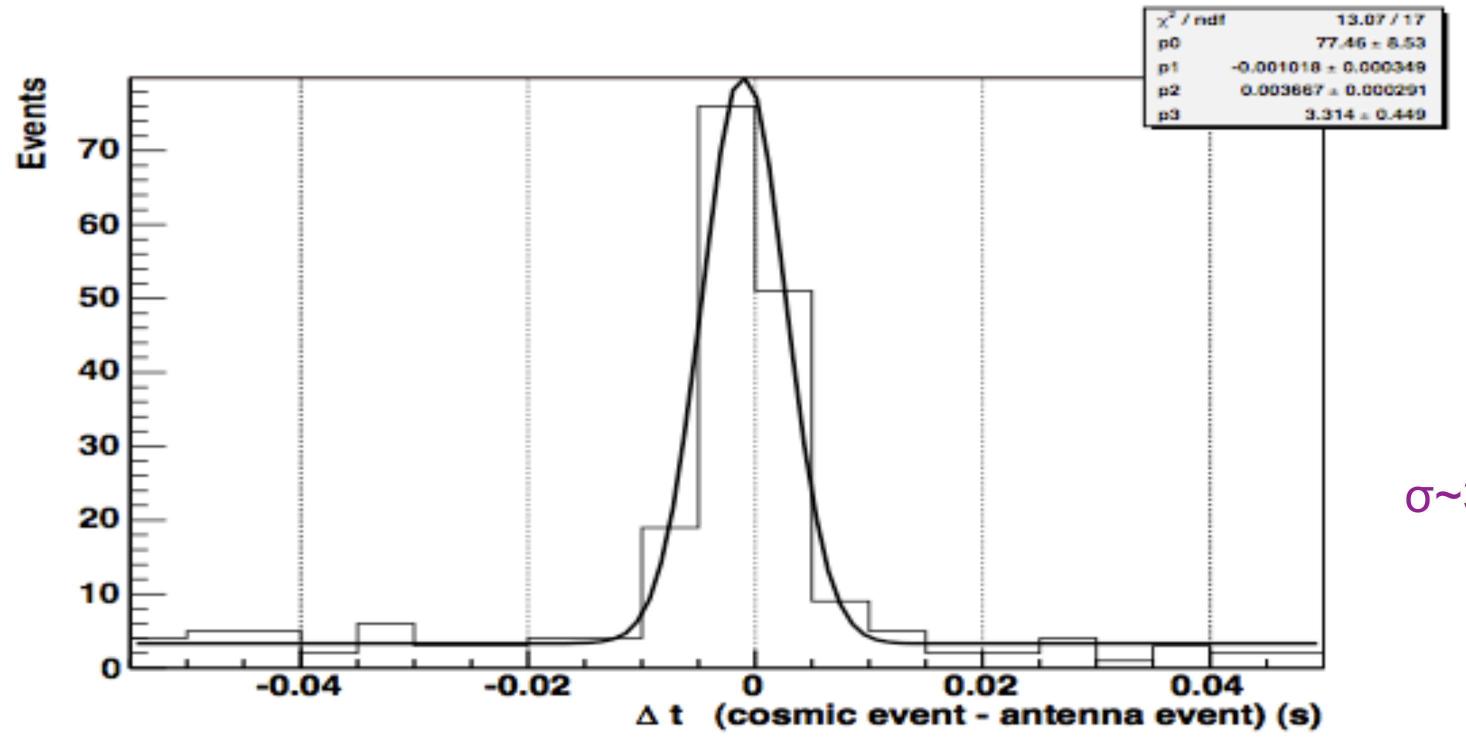


Fig. 12. EXPLORER 2003-2006 : Time difference (seconds) between cosmic rays with $\Lambda \geq 100 \frac{particles}{m^2}$ and the maximum of the filtered antenna signal, with a cut $E \geq 36\ T_{eff}$. The fit with a gaussian , with parameters p0=peak, p1=mean, p2=σ and a constant background p3, gives $\sigma = 3.7ms$. The value of the mean (-1±0.35 ms) should be compared to the expected value of -0.6 ms due to the delay of the antenna electronic chain.

σ~3.7ms