How the CeC was conceived

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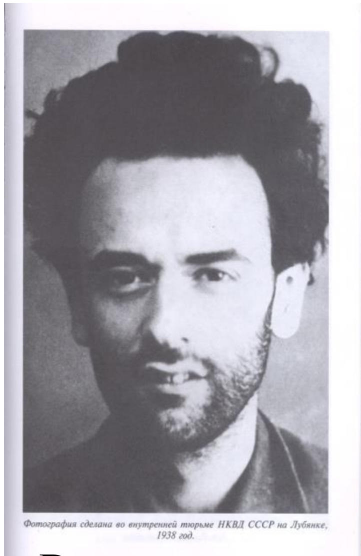
OUTLINE

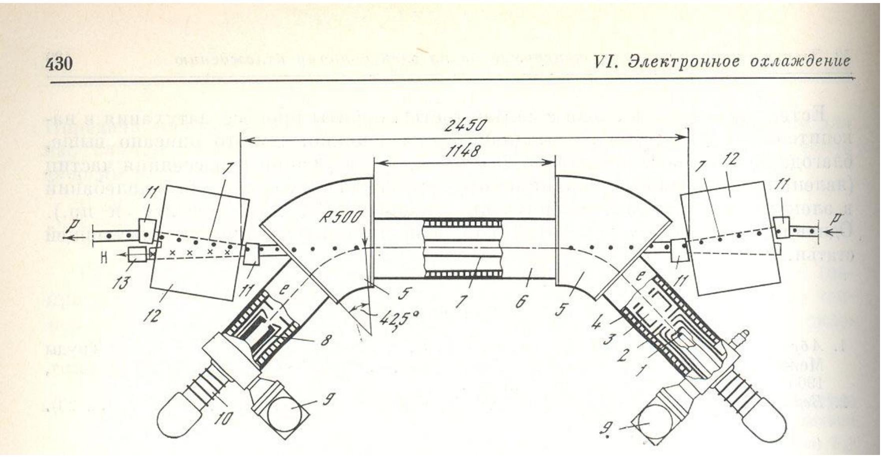
- EC idea
- EC shelf vs plasma
- Magnetized EC
- Plasma shield in EC
- EC enhancement by MWI as Coulomb log bifurcation
- Going for MWI species
- Understanding the limitations
- Difficult road to bright future…

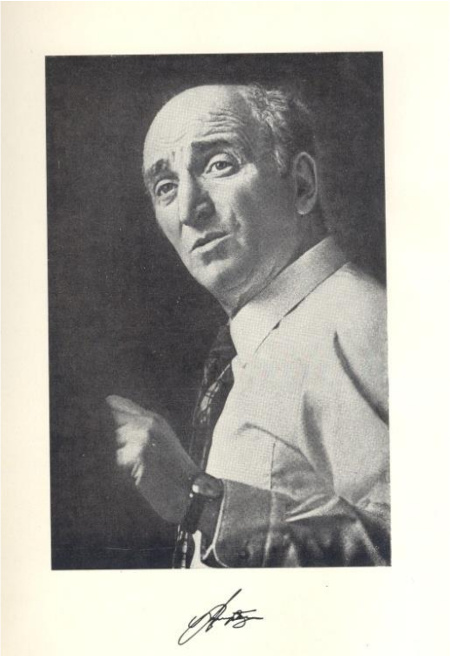
ELECTRON COOLING:

The thermostat of a relativistic engineer



Do not renounce from prison and money bag…





Landau liked to call me "The relativistic engineer". I am very proud of that.

Gersh Budker

- **<u>Kinetic equation</u> (plasma relaxation) was derived by Landau in 1937. But… can it work for charged beams? It does! Yet very interesting and important phenomena have been discovered**
(magnetized cooling, super-deep cooling, cristaline beams…)
- **<u>EC and IBS</u>: similar equations…**

EC as plasmas relaxation

Boltzman →Fokker-Plank equation with binary collisions integral of Landau results in thermal relaxation between ions and electrons:

$$\frac{dT}{dt'} = -\frac{8\sqrt{2\pi}}{3}\eta\frac{n_e' Z^2 e^4 L}{mM}\frac{T - T_e}{\left(\frac{T}{M} + \frac{T_e}{m}\right)^{3/2}}$$

$$\vec{F}(\vec{\upsilon}) = -\frac{4\pi Z^2 n_e' e^4 L}{m\upsilon^3}\vec{\upsilon} \quad for \quad \upsilon \gg \upsilon_{eT}$$

$$L(u) = \log\frac{mu^3\tau_{eff}}{Ze^2}, \qquad \tau_{eff} = \min\left\{\frac{1}{\omega_e}, \frac{l}{\gamma\beta c}\right\}$$

Drag force of a fast ion

- $\vec{F}(\vec{v}) = -\frac{4\pi Z^2 n_e' e^4 L}{m v^3}\vec{v} \quad for \quad v \gg v_{eT}$

$$L(u) = \log\frac{m u^3 \tau_{eff}}{Z e^2}\,, \qquad \tau_{eff} = \min\left\{\frac{1}{\omega_e}, \frac{l}{\gamma\beta c}\right\}$$

- Magnetized cooling: $r_L << \sigma_\perp$

$$\vec{F}(\vec{v}) \sim -\frac{4\pi Z^2 n_e' e^4 L}{m v^3}\vec{v} \qquad for \quad v \gg \frac{\Delta\gamma_e}{\gamma} c$$

Is the EC 100% same process as plasma relaxation?

- Interaction time is limited by the cooling section length
- While an ion excites electron plasma effectively in dynamical shield radii which can be much larger compared with electron Debay parameter

BALESCUE-KLIMONTOVICH THEORY FOR DRAG FORCE IN PLASMAS

- *Taking into account stability of a normal plasma, these professors have derived the following formula for the drag force:*
- $\vec{F} = -\frac{Z^2 e^2}{2\pi^2} \int d^3k \, \frac{\vec{k}}{k^2} \frac{\operatorname{Im} \varepsilon_{\vec{k}}(\vec{k}\vec{v})}{\left|\varepsilon_{\vec{k}}(\vec{k}\vec{v})\right|^2}$
- Assumption about Landau damping of the ignited plasma waves is valid for the conventional real plasmas
- But it is not so in our case of the cooling electron beam…

Vlasov- Landau Theory of the Plasmas Waves

- Prof. Vlasov has incepted his the self-consistent method to describe plasma waves
- Prof. Landau has found damping of the plasma waves
- However, this damping is not effective in the area beyond the electron Debay radii – during the flight time of our beams through the cooling section…
- Namely , this circumstance is forcing one to take into account the wave mode of electron plasma excitation by an individual ion… - effectively in the sphere of the dynamical shield for a fast ion…

CONTRIBUTION OF THE TRANSIENT PROCESS IN THE E-BEAM

/Correct theory of the collective response for EC/

Formula for drag force have derived in my Soviet Doctoral Thesis (1978):

- $\vec{F}(t) = -\frac{Z^2e^2}{2\pi^2}\int d^3k\,\frac{\vec{k}}{k^2}\left\{\frac{\mathrm{Im}\,\varepsilon_{\vec{k}}(\vec{k}\vec{v})}{\left|\varepsilon_{\vec{k}}(\vec{k}\vec{v})\right|^2} + i\sum_s\left[\frac{\exp(-i(\omega-\vec{k}\vec{v})t)}{(\omega-\vec{k}\vec{v})\partial\varepsilon_{\vec{k}}(\omega)/\partial\omega}\right]_{\omega=\omega_s}\right\}$

The second term is the contribution of the transient field excited by an ion. Now, imagine that electron plasma is unstable. Then what?...

RETURN TO THE TRANSIENTS…

AS COULOMB LOG BIFURCATION

Electric field ignited by an ion in a homogeneous co-moving electron beam:

$$\vec{E}(\vec{r},t) = -\frac{Ze}{2\pi^2}\int d^3k\,\frac{\vec{k}}{k^2}\left\{\frac{\mathrm{Im}\,\varepsilon_{\vec{k}}\left(\vec{k}\vec{v}\right)}{\left|\varepsilon_{\vec{k}}\left(\vec{k}\vec{v}\right)\right|^2} + i\sum_s\left[\frac{\exp\left(-i\left(\omega-\vec{k}\vec{v}\right)t\right)}{\left(\omega-\vec{k}\vec{v}\right)\partial\varepsilon_{\vec{k}}(\omega)/\partial\omega}\right]_{\omega=\omega_s}\right\}\exp\left(i\vec{k}(\vec{r}-\vec{v}t)\right)$$

- $At\ Im\omega_s > 0,$

$the\ transient\ (second)\ part\ grows\ along\ the\ cooling\ section$

$$\vec{E}(\vec{r},t) \Rightarrow -\frac{Ze}{2\pi^2}\int d^3k\,\frac{i\vec{k}}{k^2}\sum_s\left[\frac{\exp\left(-i\left(\omega-\vec{k}\vec{v}\right)t\right)}{\left(\omega-\vec{k}\vec{v}\right)\partial\varepsilon_{\vec{k}}(\omega)/\partial\omega}\right]\exp\left(i\vec{k}(\vec{r}-\vec{v}t)\right)_{\omega=\omega_s}$$

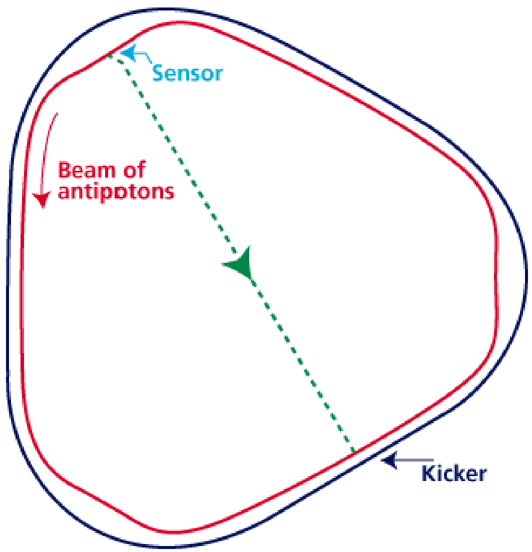
…that maybe bad…-but could'nt be even used to build the **microwave** *stochastic cooling*?! (1980)

"Is n't it the Maxwell's demon?"

(G.Budker)

STOCHASTIC COOLING:

The van der Meer's demon



It works!!

Scanned at the American
Institute of Physics

Works well for coasted low current, large emittance beams.

Can it work for bunched beams? Hardly… but demonstrated by M.Blaskewitz for lead at RHIC!

May help EIC (stacking and pre-cooling)…

Going for the MW Instability Species

- There are several possible ways to organize the MWI process in electron beam
- So the electron beam (basically fco-moving the ion beam) could serve in the all three duties: picup station, amplifier, and kicker

Understanding the Limitations

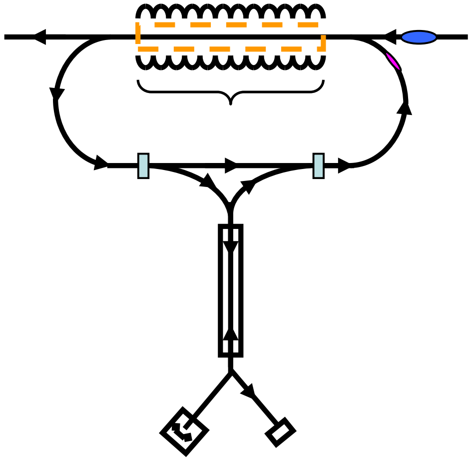
ELECTRON COOLING: PPP

-PAST & PRESENT-

Cooling of low energy beams
Relativistic cooling of p-bar
Magnetized cooling
Fast cooling
Super-deep cooling
Cooling of positrons (theory)

-PERSPECTIVES-

Cooling of positrons
Matched cooling
ERL based HEEC
Circulator-cooler ring



SUPER-PERSPECTIVE:

-COHERENT EC-

ON RISE

Revived by V.Litvinenko !

Thank you for your interest and attention!