Workshop on Beam Cooling and Related Topics
COOL 11
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Methods for optimization of the dynamics of positrons storage in the Surko trap

*__*M. Eсеев*__, *A. Kobets, I. Meshkov,*
A. Rudakov, S. Yakovenko
JINR, Dubna
***Lomonosov Northern Federal University, Arkhangelsk**

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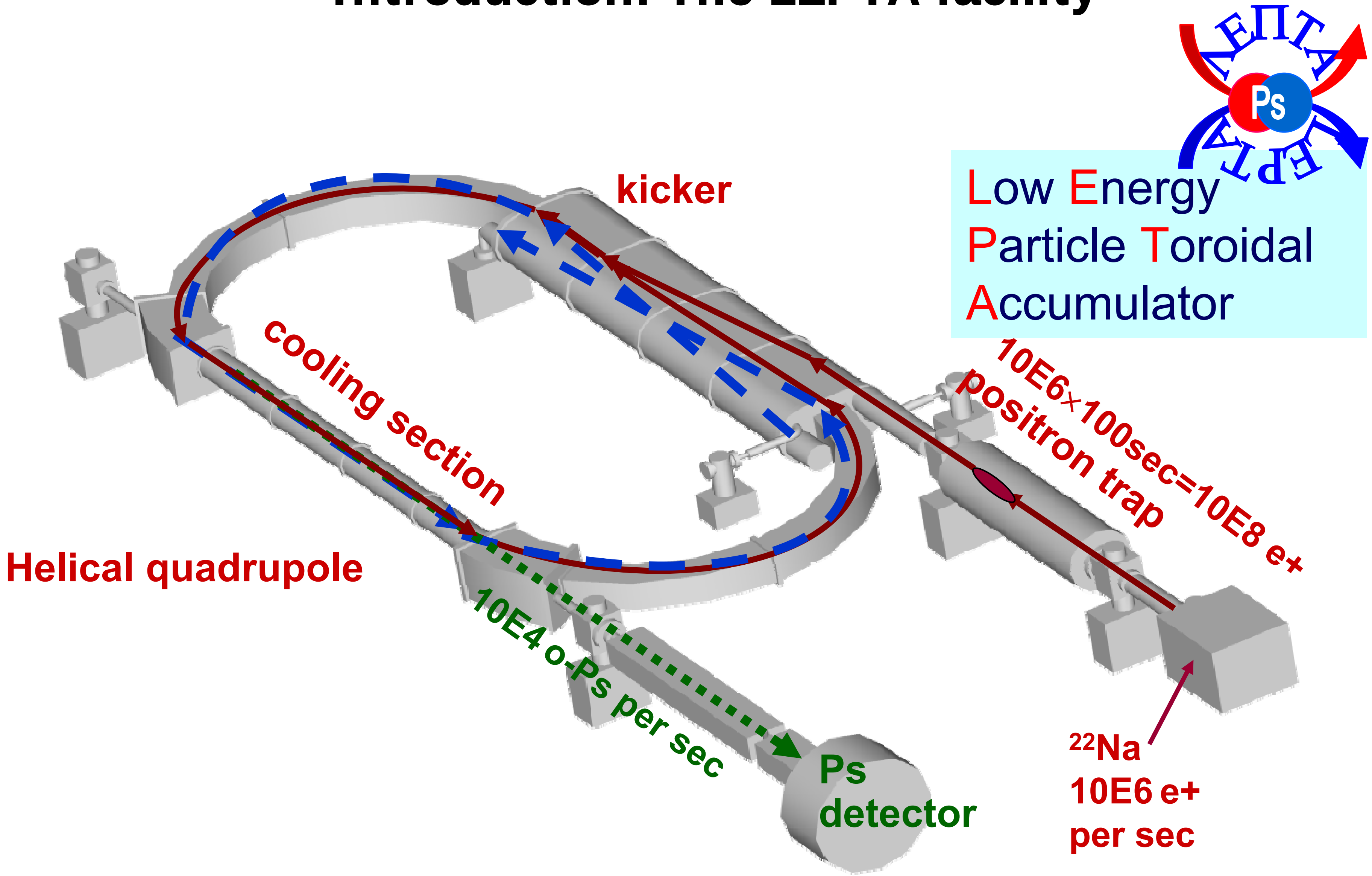
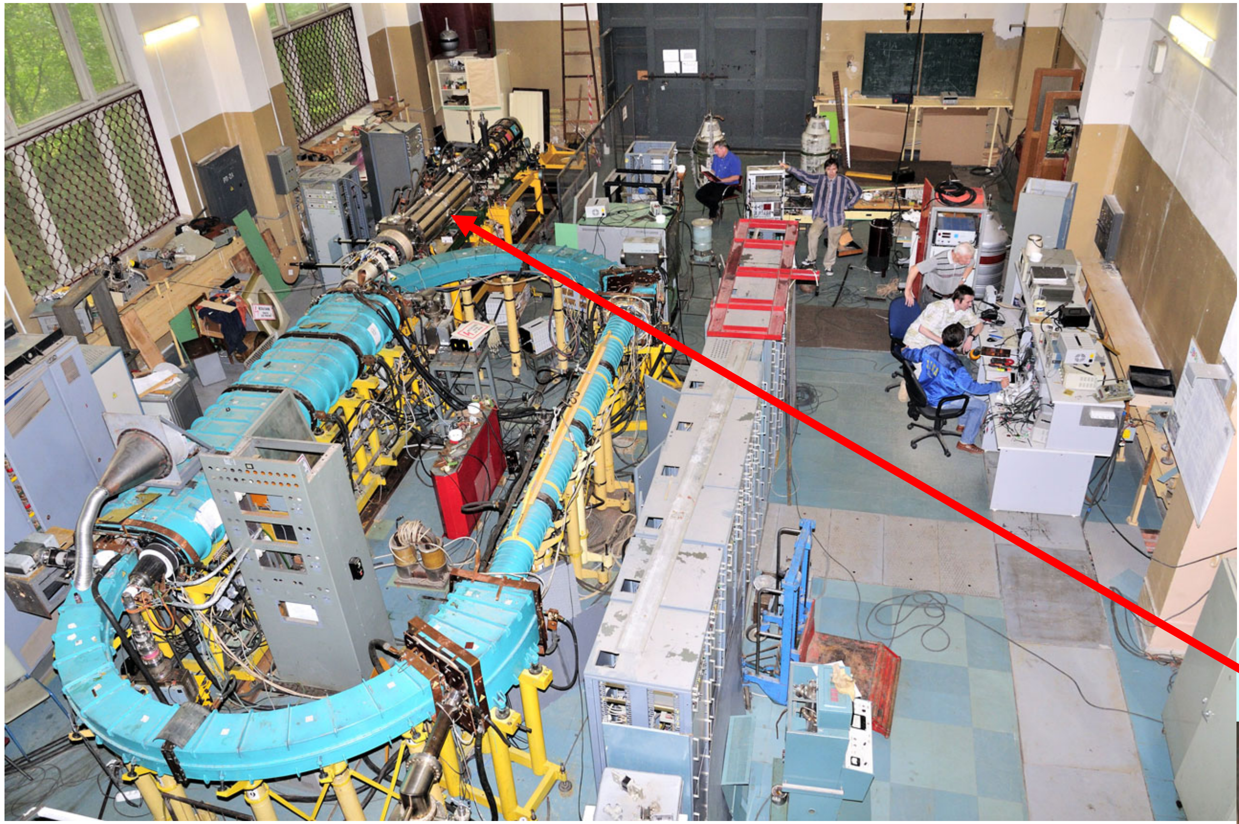
Introduction: The LEPTA facility

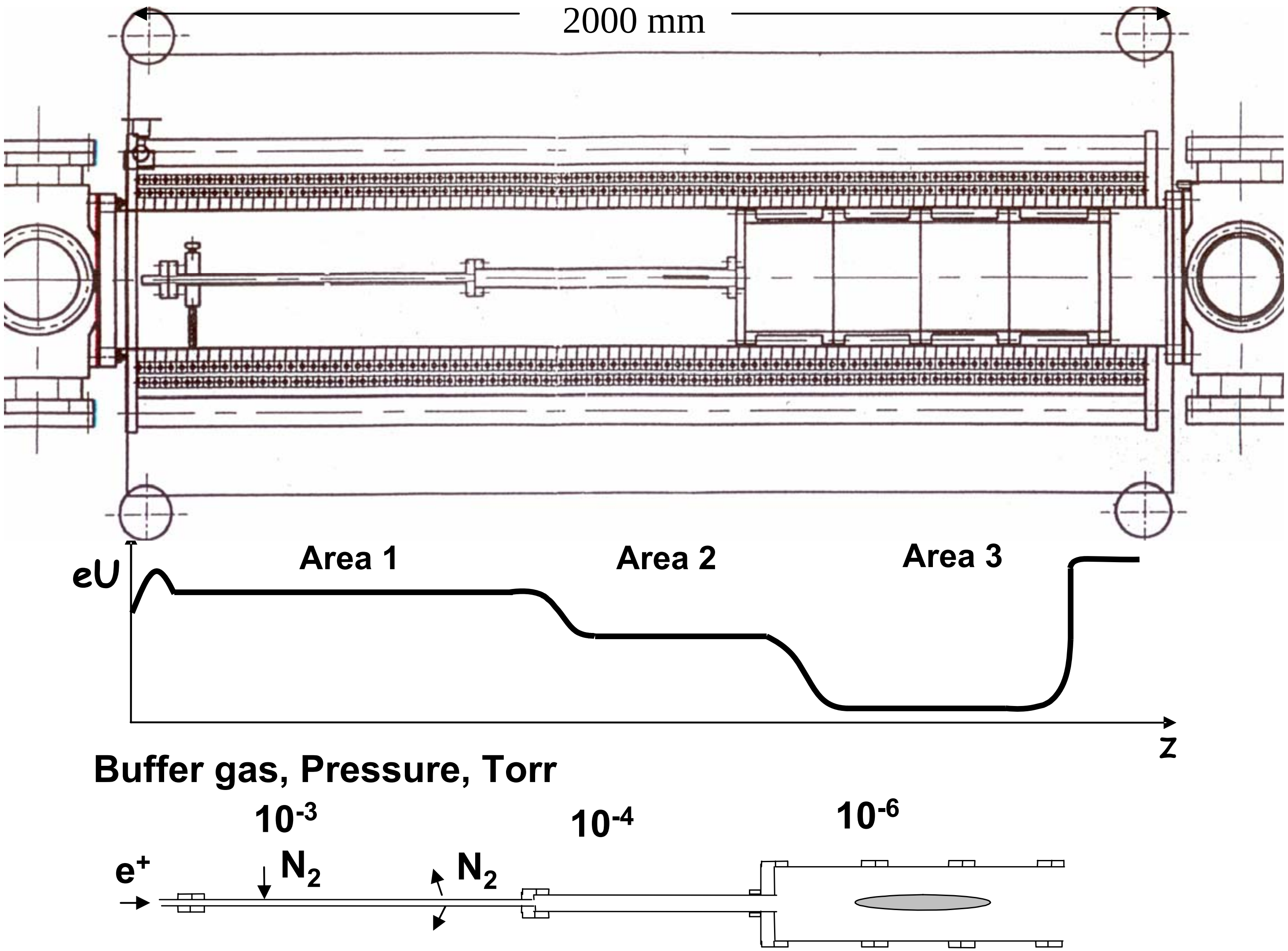


Introduction: The LEPTA facility

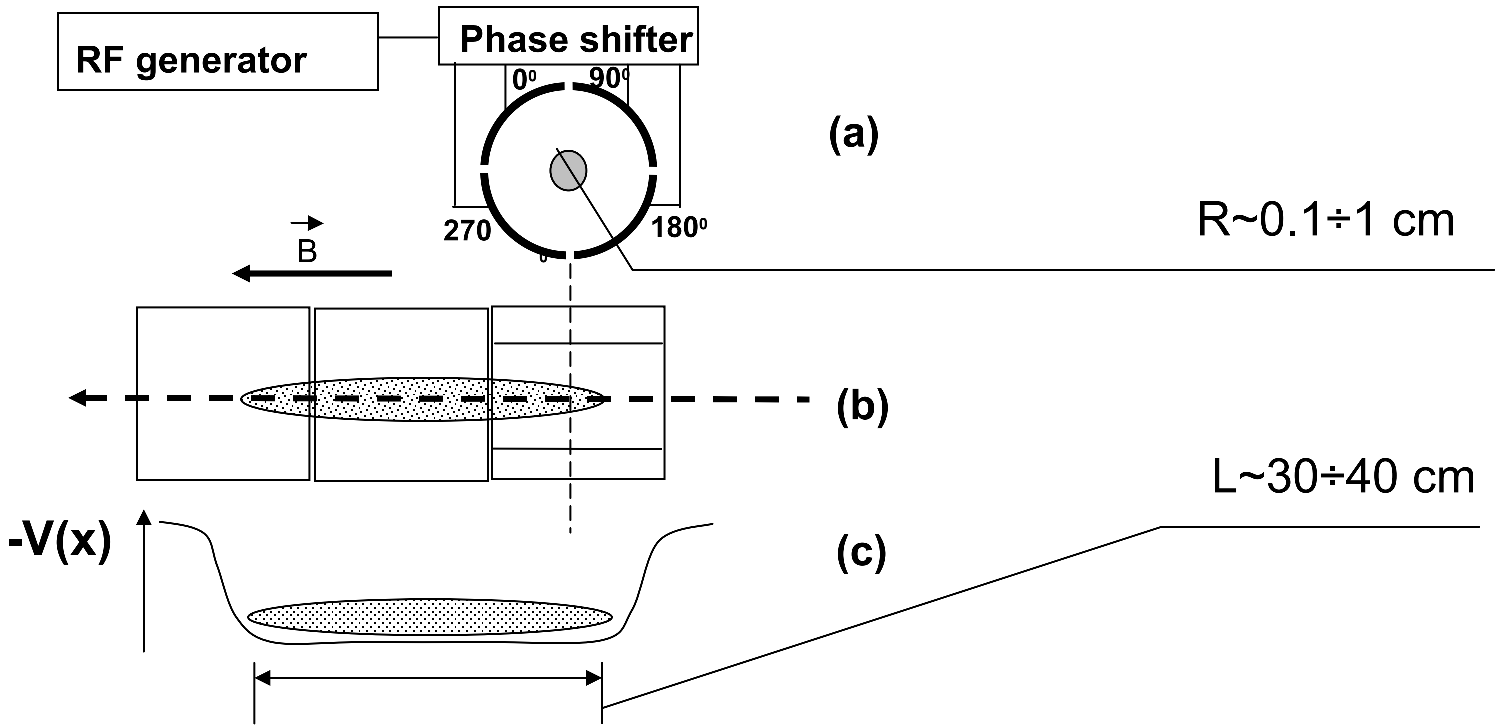


Trap & Injector

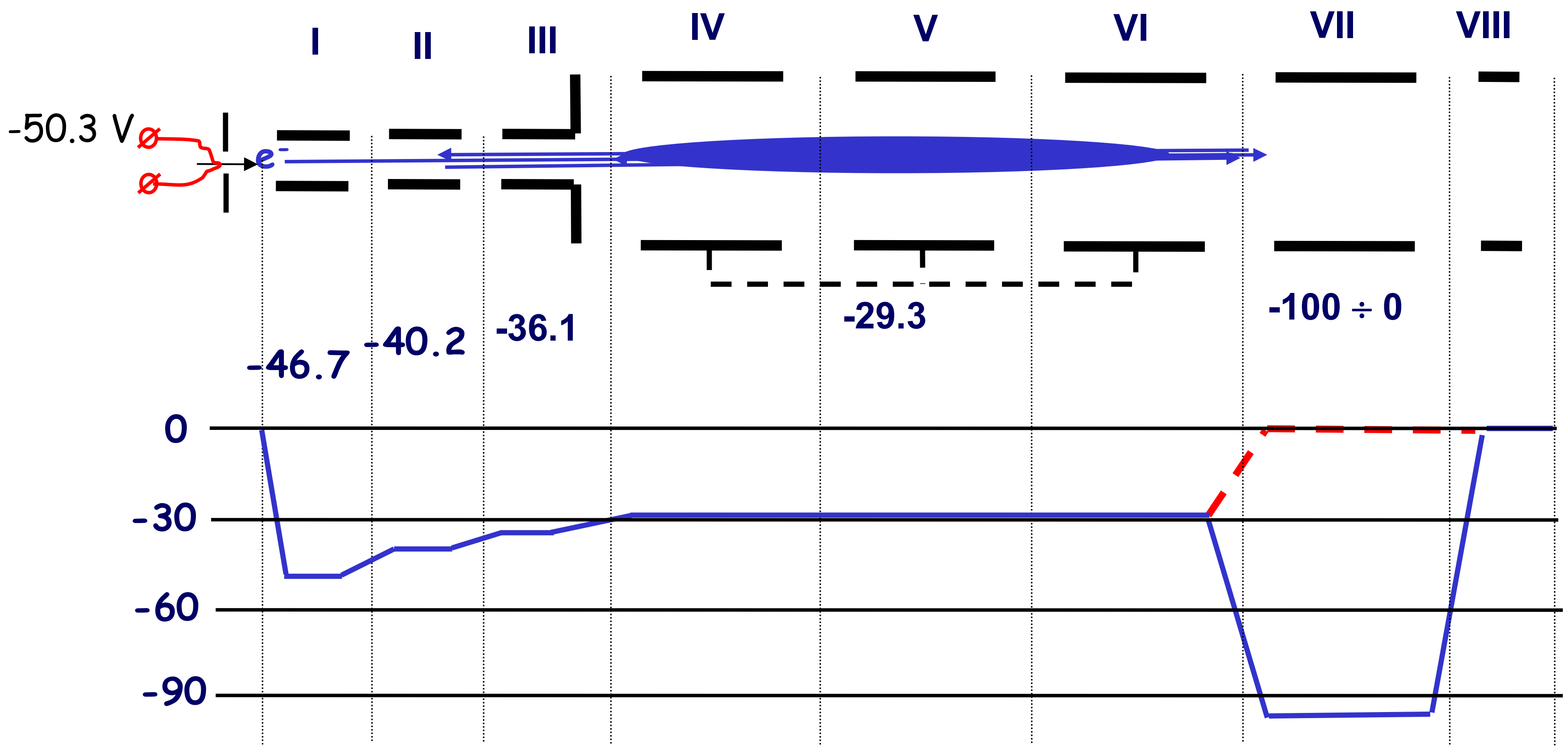
1. Surko trap and “rotating wall” technique



“Rotating wall” (RW) technique: rotating electric field at the trap entrance



Principles of electron or positron storage in the Surko trap In application to LEPTA facility

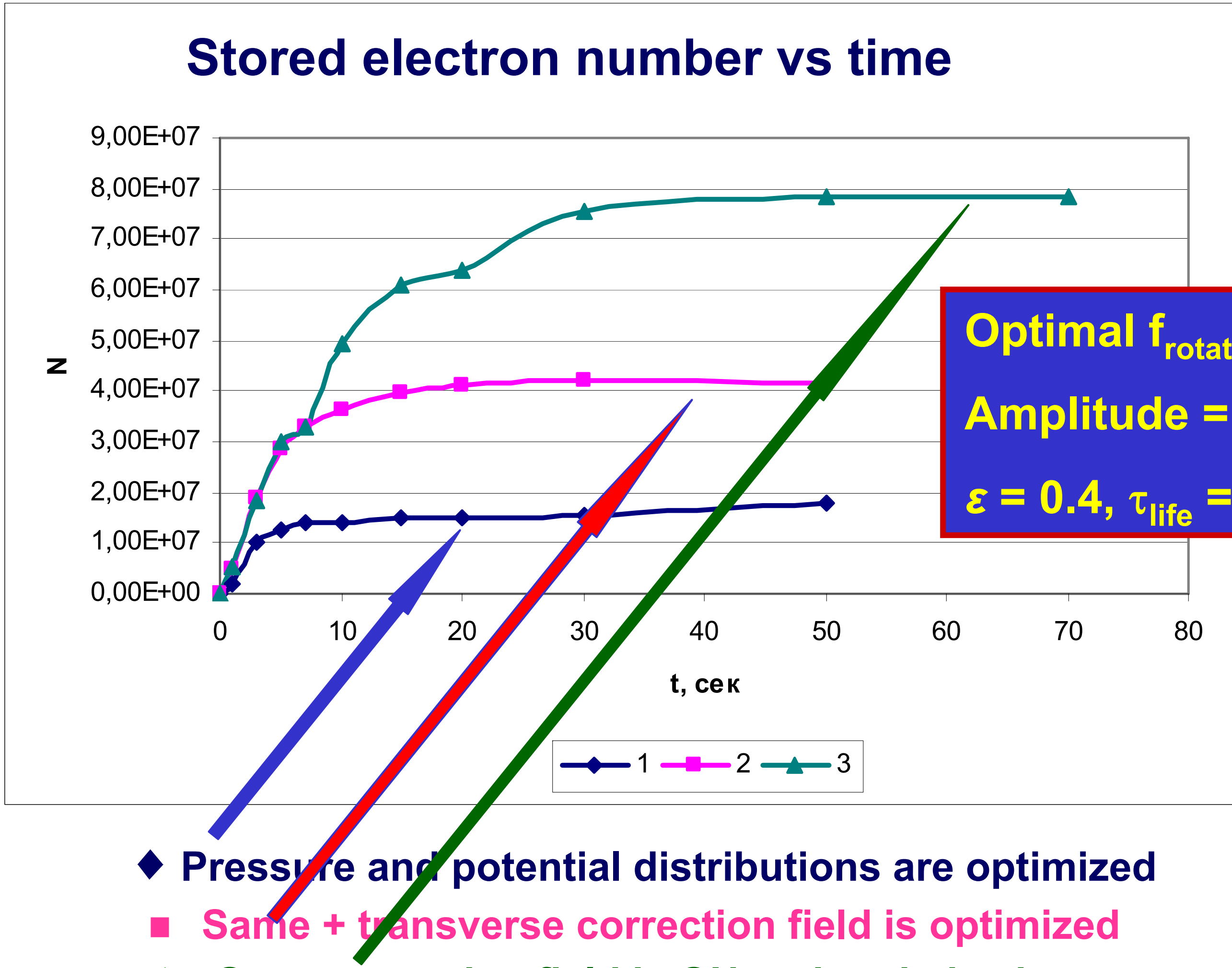


3. Experimental results of particle storage in trap with "rotating wall" (RW)

The RW effect (compression of particle bunch) has been studied experimentally

- With ions: Mg^+ and other ions (Laboratory University of California at San Diego, Prof. Clifford Surko)
  X-P. Huang et al., PRL, **78**, 875 (1997).
- With electrons:
  Anderegg, E. M. Hollmann, and C. F. Driscoll, PRL, **81**, 4875 (1998).
- With positrons:
  R. G. Greaves and C. M. Surko , PRL, **85**, 1883 (2000).
  T.J. Murphy and C.M. Shurko, Phys. Plasmas, **8**, 1878 (2001).
  J. R. Danielson, C. M. Surko, and T. M. O'Neil PRL., **99,** 135005 (2007).
- With antiprotons (Hbar production, ALPHA, CERN)
  J. R. Danielson, et al., PRL. **100**, 203401 (2008) .
  G. B. Andresen , et al., Nature, **468**, 673 (2010).

Our experimental results of electron storage



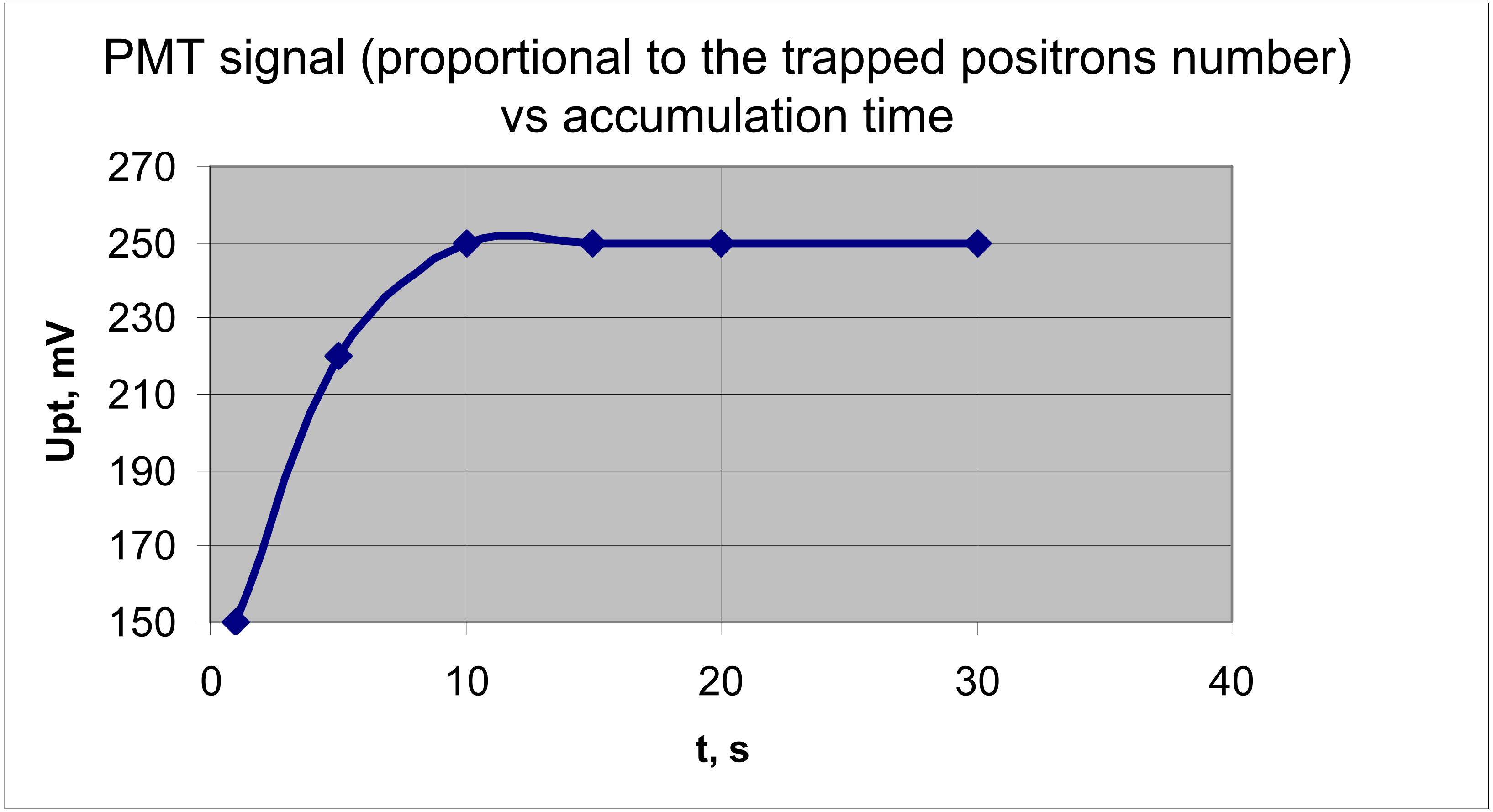
Optimal $f_{rotating}$ = 600 kHz,

Amplitude = 1 V,

ε = 0.4, τ_{life} = 80 s

- ◆ **Pressure and potential distributions are optimized**
- ■ **Same + transverse correction field is optimized**
- ▲ **Same + rotating field is ON and optimized**

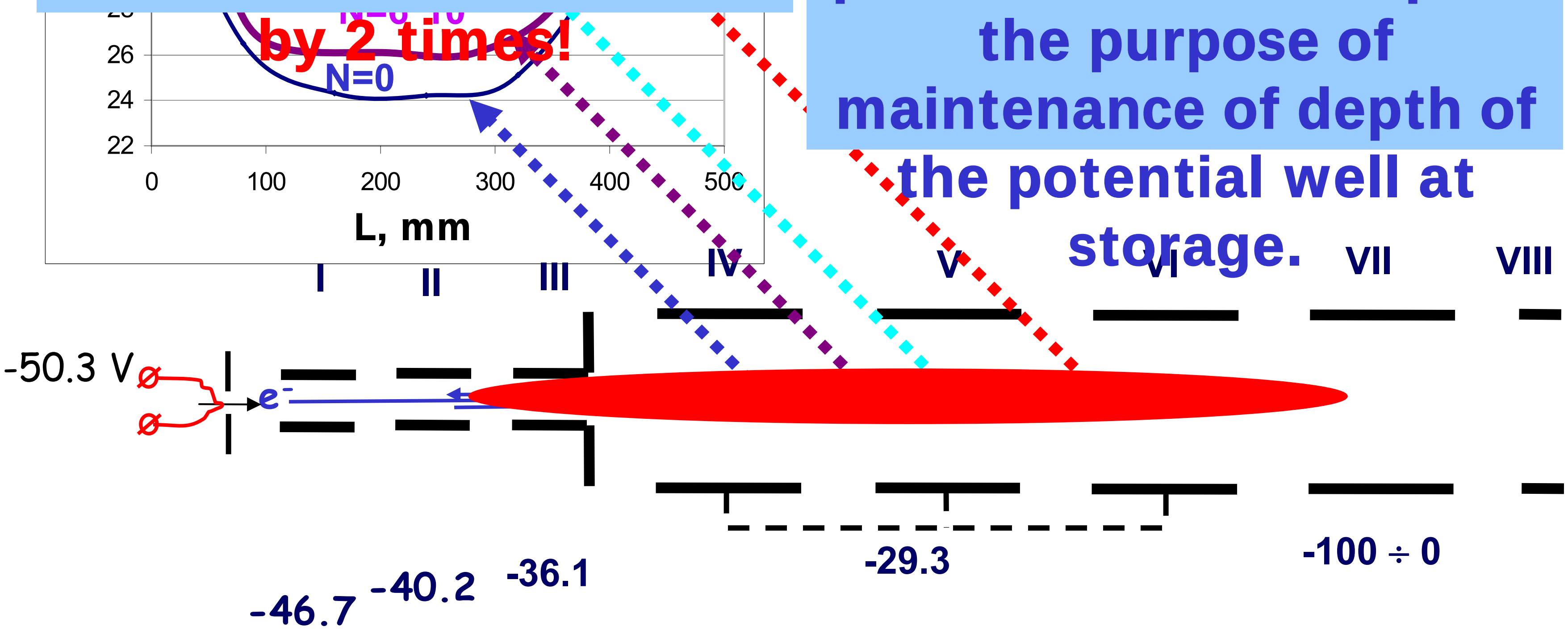
First experiments on slow positron accumulation in the positron trap have been performed.
June 2010



Particle storage and "the space charge limit"

"Dynamical control" of the potential allows us to increase the particle number in the bunch ~ by 2 times!

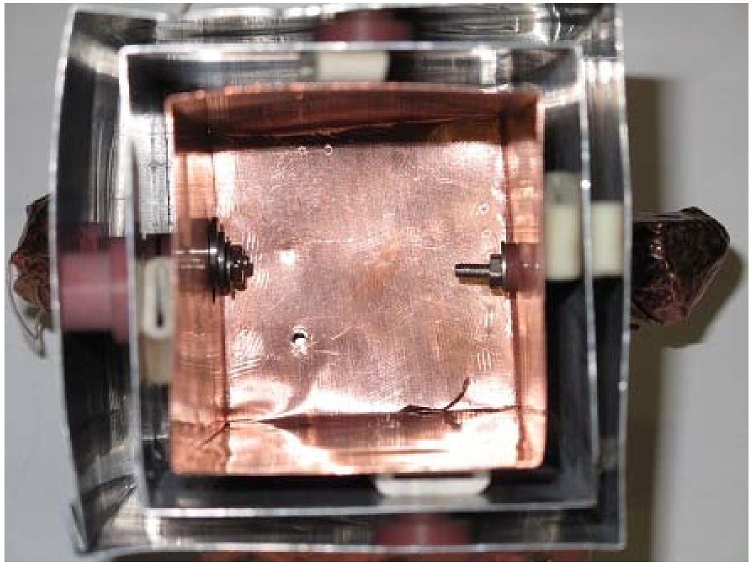
"Dynamical control" regime is gradual magnification of locking potentials of the trap for the purpose of maintenance of depth of the potential well at storage.

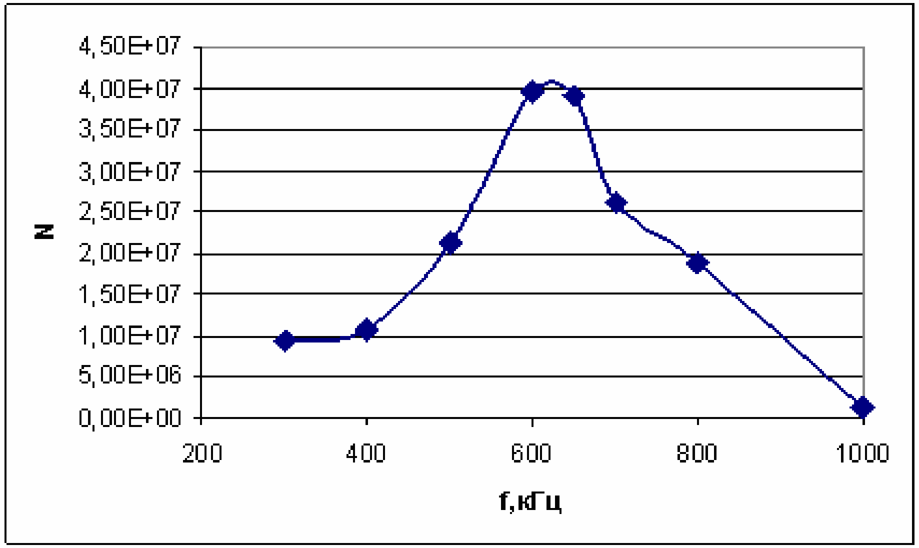


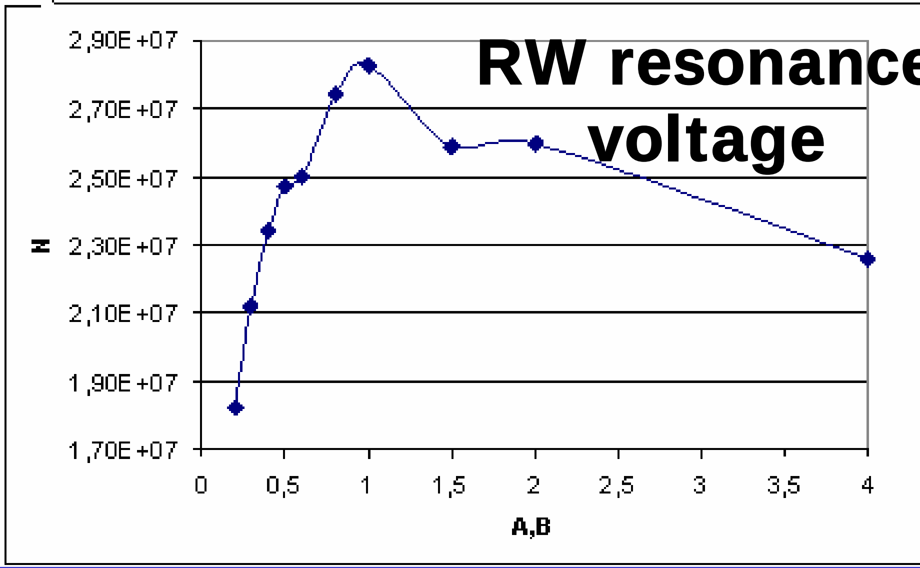
Dependence of depth of the potential well on number of the stored up electrons

experimental results of electron storage, RW role

RW resonance, frequency



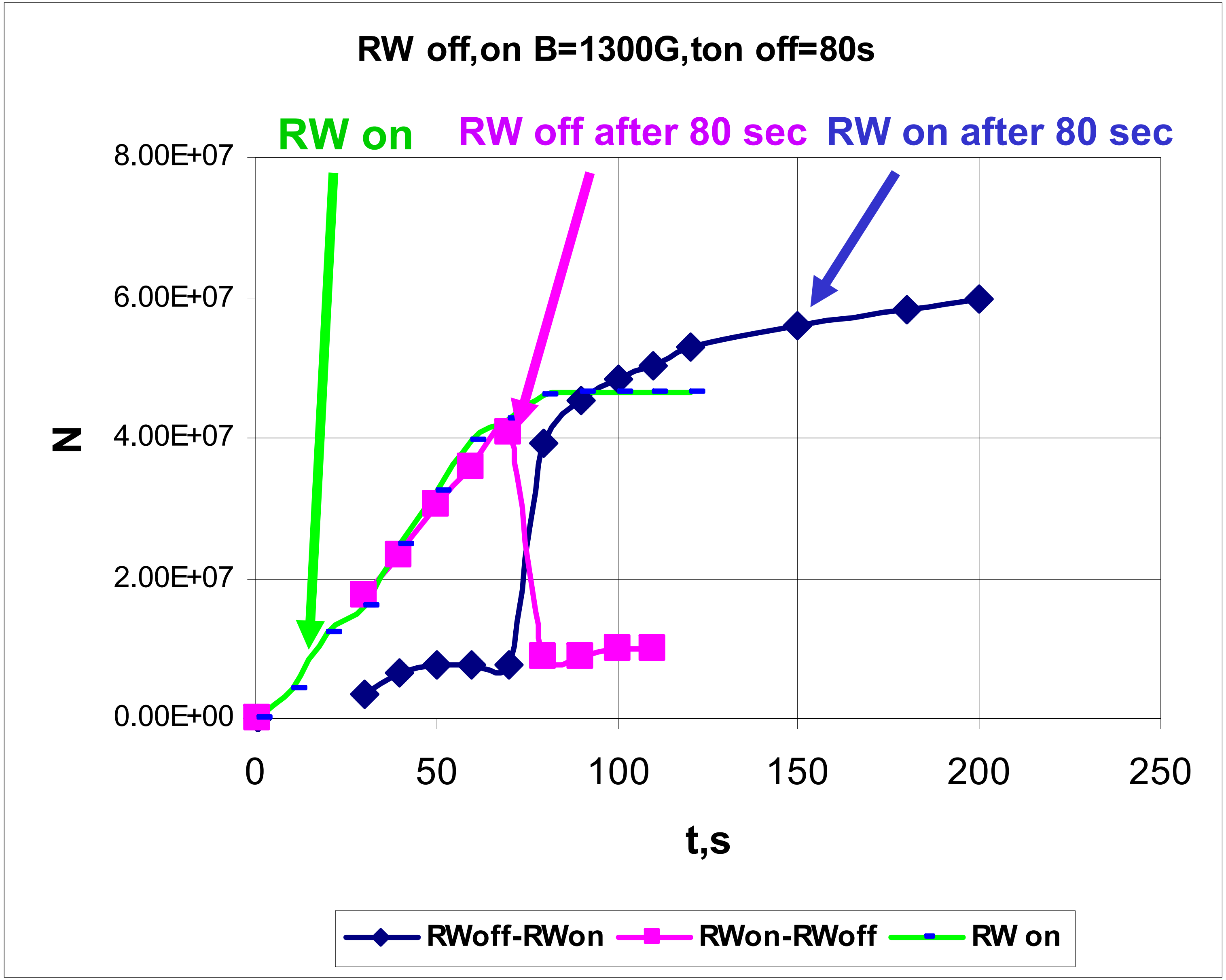




RW resonance voltage

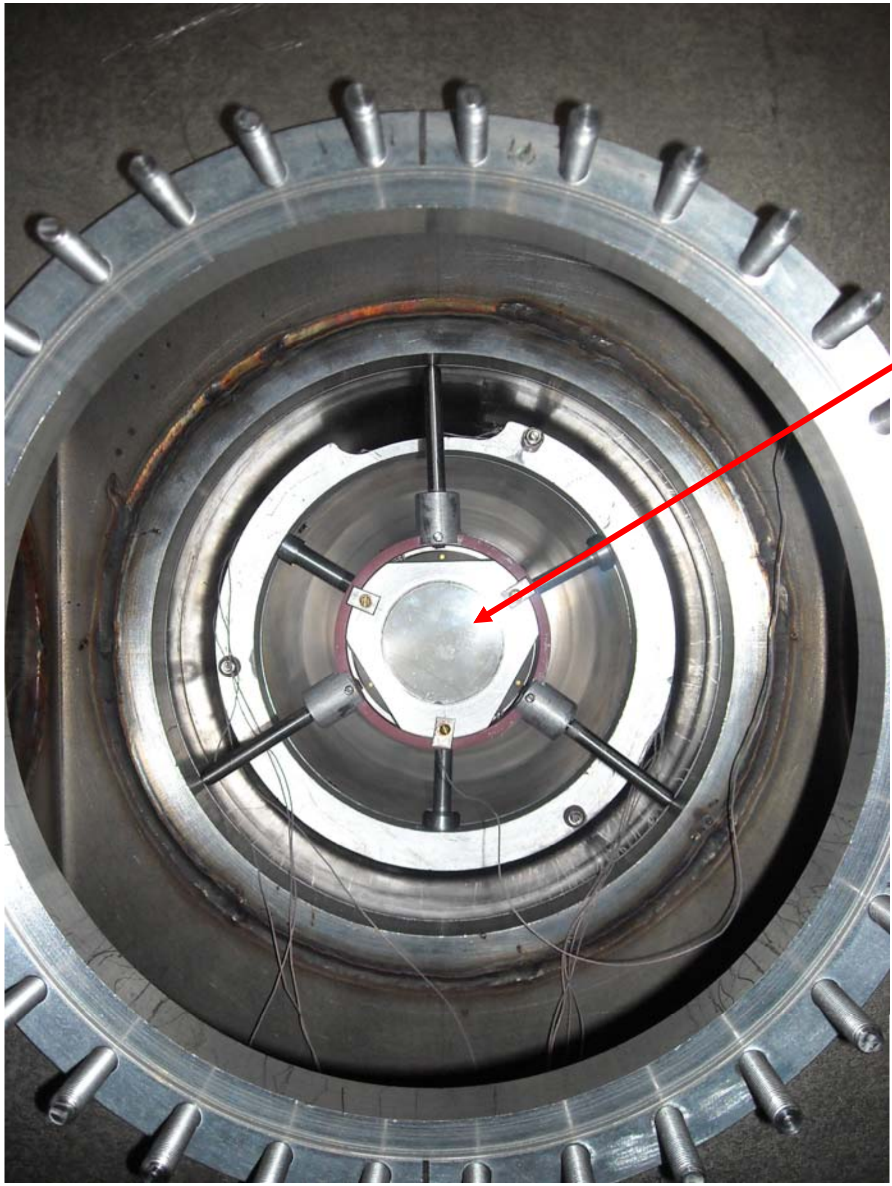
Stored electron number was measured by pulsed extraction of electrons to the collector

Experimental results of particle storage in trap with “rotating wall” (RW)

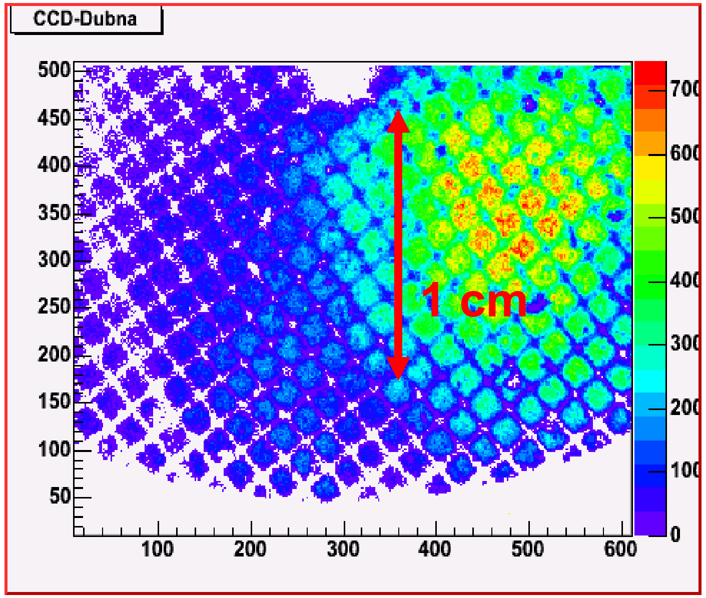


Experimental results of particle storage in trap with “rotating wall” (RW)

Transverse bunch profile, CCD camera



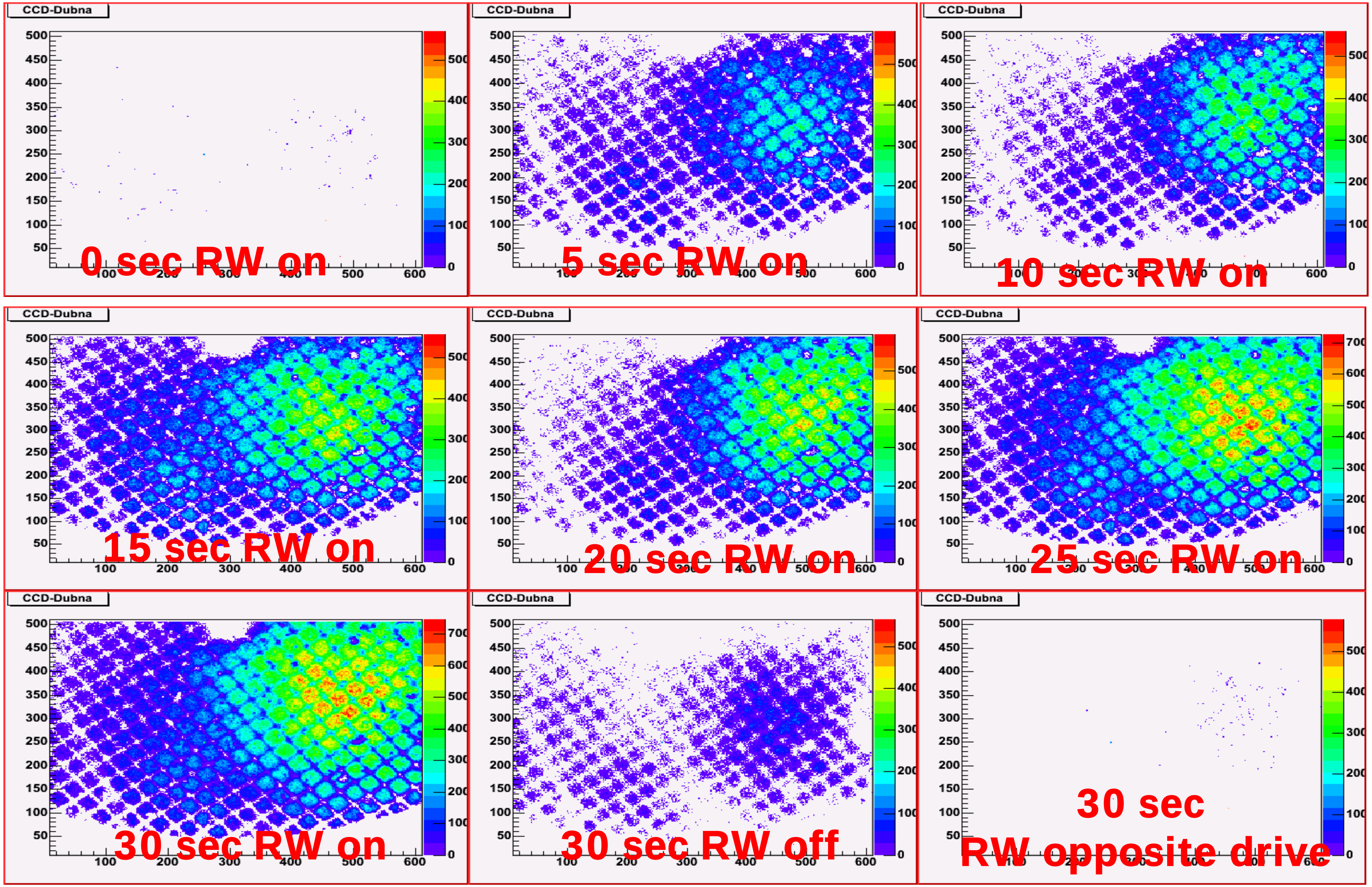
MCP + Luminescent screen + CCD camera*)



***) Courtesy of Budker INP colleagues**

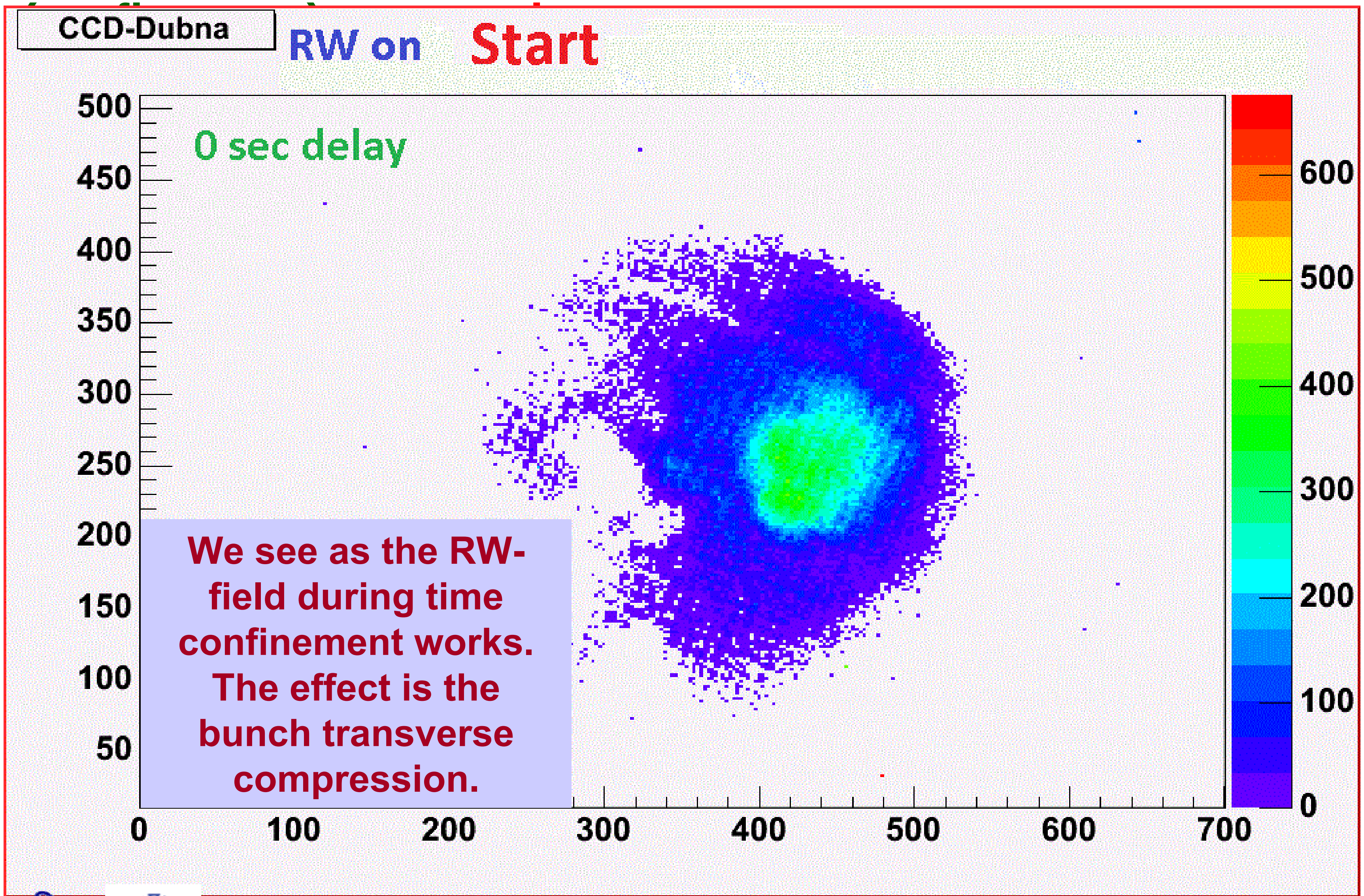
Experimental results of particle storage in trap with “rotating wall” (RW)

Dynamics of extracted bunch profile

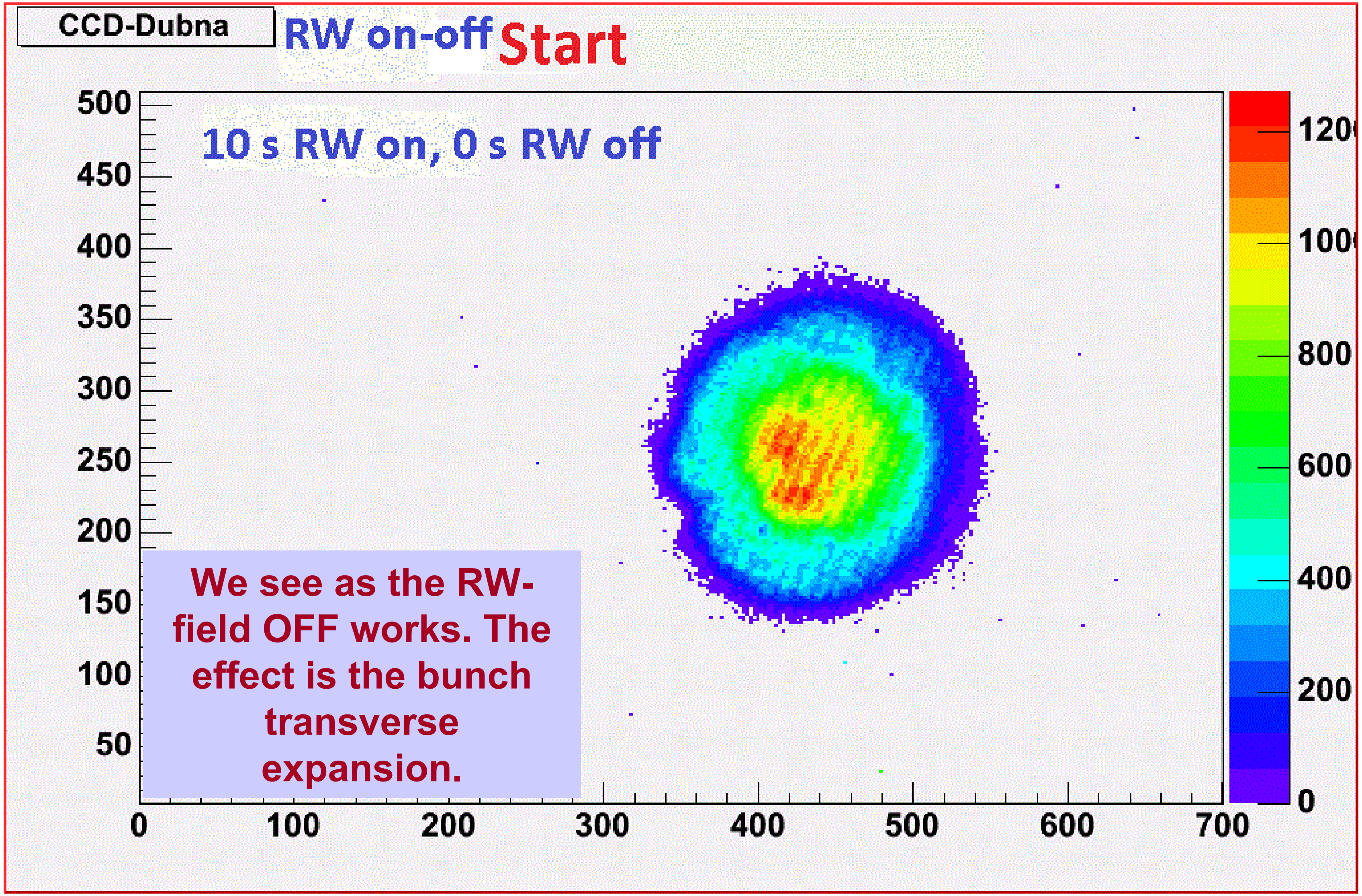


RW influence on electron storage, RW on

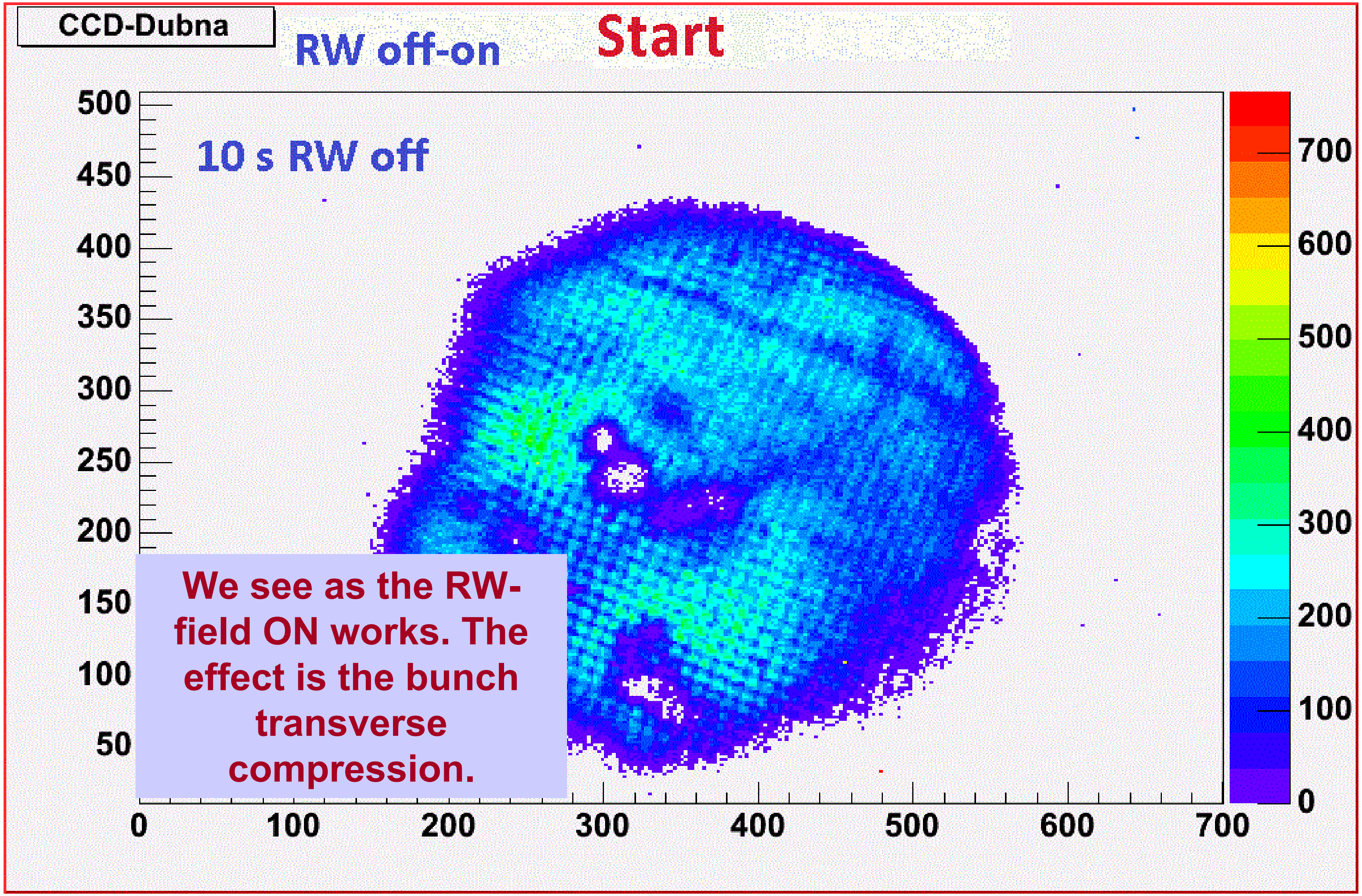
Injection and accumulation (30 s)→ injection off →delay



Injection and accumulation RW on (30 s)→ injection off →delay (confinement) RW off →extraction



Injection and accumulation RW off (30 sec)→ injection off →delay (confinement) RW on →extraction



erimental results of particle storage in trap with “rotating wall” (RW)

Electron bunch compression.
Gaussian distribution of the density

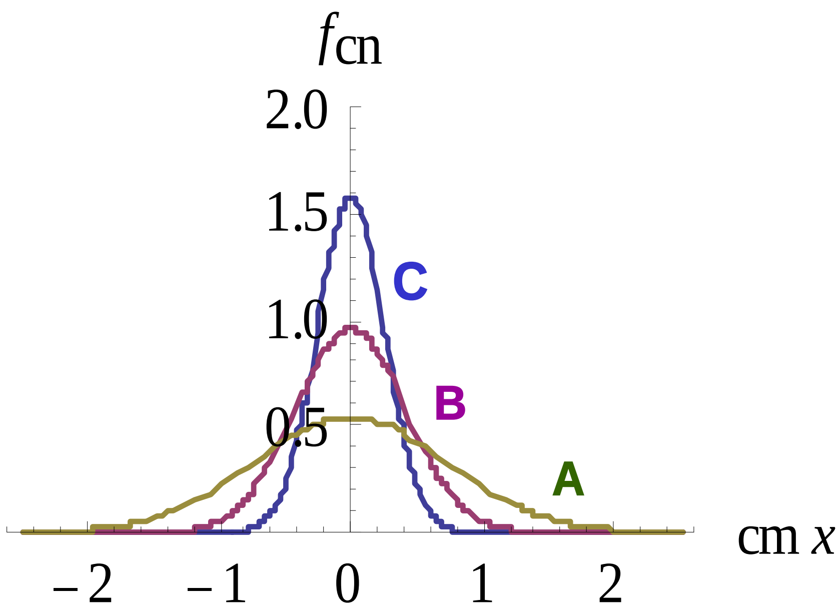
Fitting of transverse plane CCD photo

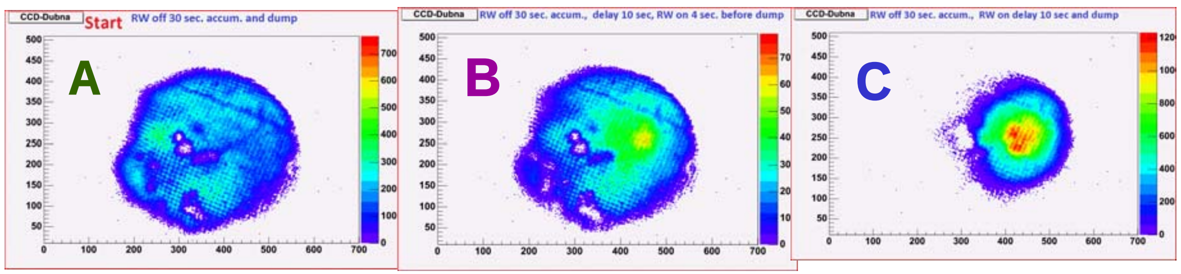
$$n(r) = n_0 G(A) \exp\left[-(r/\sigma)^2\right]$$

$$G(A) = (\pi A)^{-1/2} \exp[-A]$$

$$A \equiv -(e/T)\left[V_c - V_{ex} - \varphi(r)\right]$$

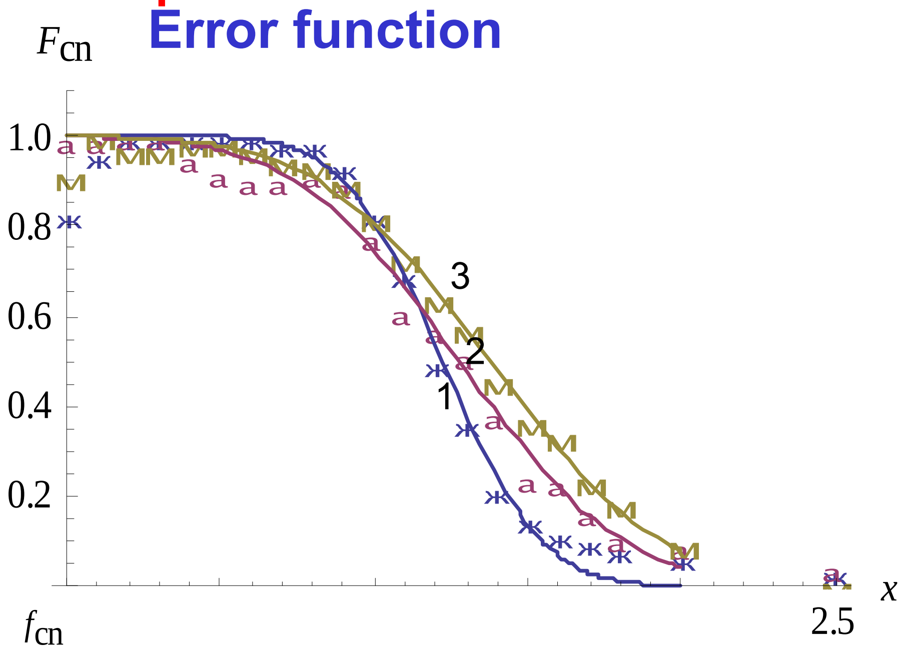
$$\sigma = 2\lambda_D$$

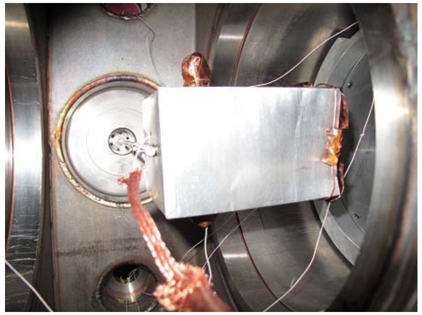




Measurements of the bunch size and density distribution by collector current

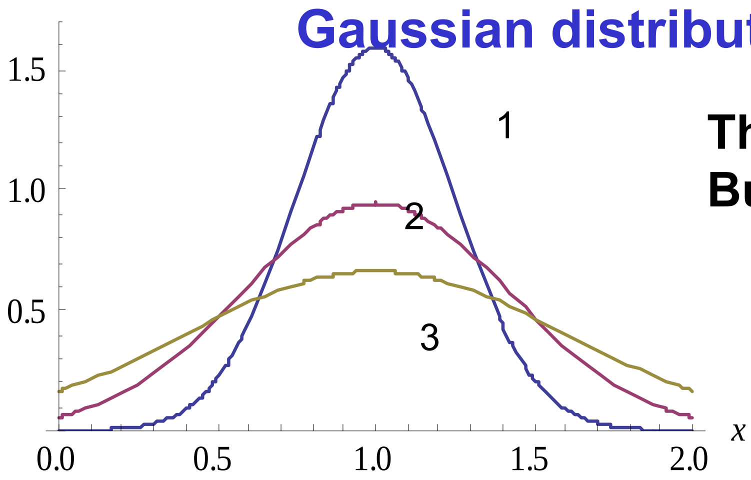
Beam profile was scanned with movable collector at the trap exit





Normal distribution electron current at various positions of the collector

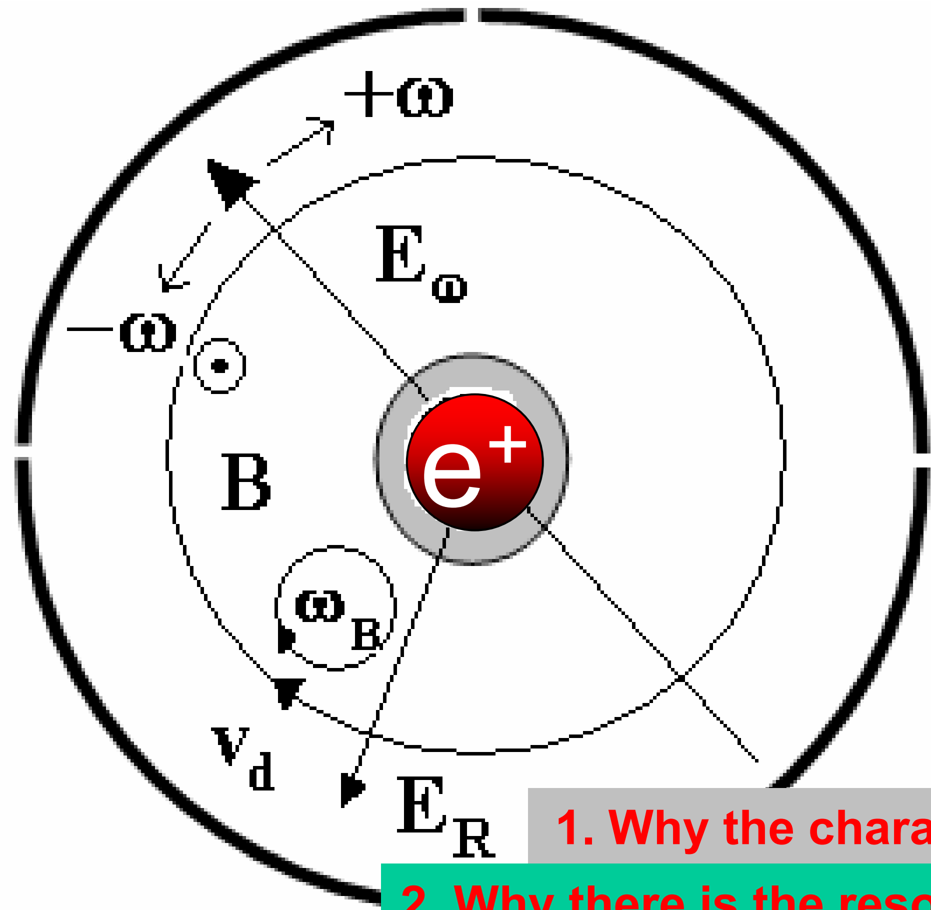
1. RW on 30 sec
2. RW on 30 sec, off 5 sec
3. RW on 30 sec, off 10 sec



The result of fitting with Gaussin function. Bunch expansion at RW-field off

Theory and numerical simulations of particle motion in the trap

Transverse motion of the trapped particle



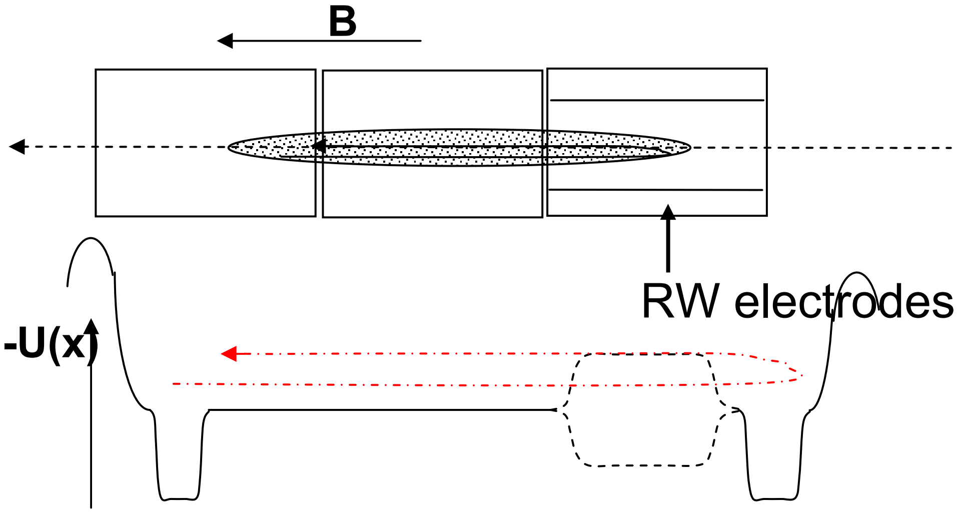
E_ω, V/cm	0.05
f_{RW}, kHz	**600**
n_e, cm^{-3}	$10^7 \div 10^8$
ω_p, c^{-1}	**$3.5 \cdot 10^7 \div 2 \cdot 10^8$**
B, Gauss	1200
ω_B, c^{-1}	**$2.1 \cdot 10^{10}$**
p_{N2}, Torr	$2.25 \bullet 10^{-6}$
R, cm	0.1÷2
L, cm	30÷40

1. Why the characteristic frequencies such different?

2. Why there is the resonance on frequency of the RW field?

3. Why the direction of rotation of the RW field is important?

Longitudinal motion of the trapped particle



$B_{long} \parallel E_{long}$

The particle injection in the storage region trap with initial energy $E_{part} \approx 1\ eV$

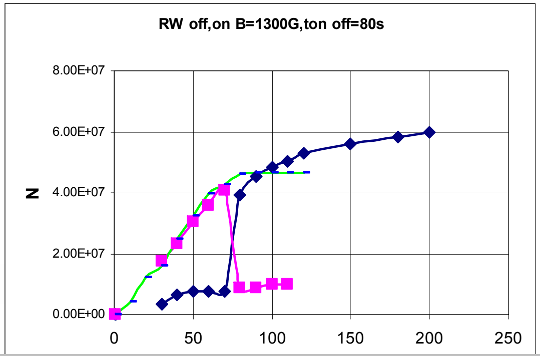
Then the particle in inelastic collisions with molecules of buffer gas is cooled to a room temperature $E^{cool}_{part} \approx 0.025\ eV$

p_{N2} , 2.25·10-6 Torr

$L \sim 30 \div 40$ cm, $T_{long} = 2L / \upsilon_{long}$ $f^{res}_{RW} \approx T^{-1}_{long}$

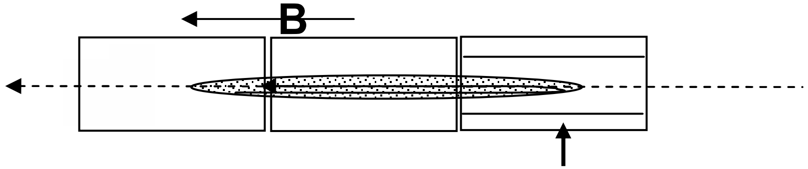
4. Why frequency of the longitudinal motion will be compounded with frequency of the RW field?

5. What role of buffer gas intro storage region?

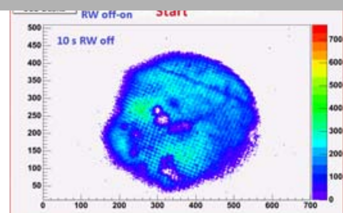


Other questions:

6. Why the RW field increments quantity of the confinement up particles and the bunch lifetime?



7. Why the segmented RW-electrodes should occupy not all storage region? (less than half of part of length of region storage*, in our experiments - the one third part)



8. Why the RW field compression the bunch?

*J. R. Danielson and C.M. Shurko, Phys. Plasmas, 13, 055706 (2006).

Solution of equations of particle bunch dynamics in the trap

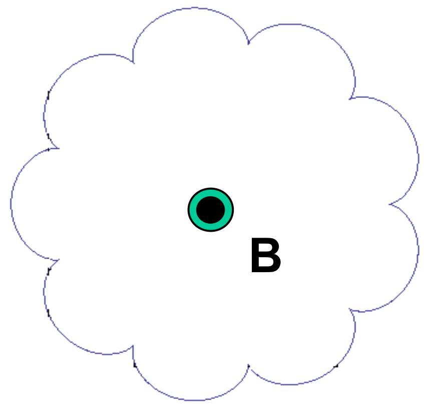
Transverse positron motion in the crossed B-field and RW E-field and E-field of the bunch space charge

$$\ddot{\xi} + i\omega_B \dot{\xi} - \eta\xi = \varepsilon e^{-i\omega_{RW} t}$$

$$\omega_B = \frac{eB}{mc} \qquad \omega_p = \sqrt{\frac{4\pi e^2 n}{m}} \qquad \varepsilon = \frac{e}{m} E_\omega^0$$

$$\eta = \frac{e}{m} E_R^0 = 2\pi \frac{e^2 n}{m} = \frac{\omega_p^{\ 2}}{2}$$

$$\omega_{RW} = \frac{\omega_B}{2}\left(1 \pm \sqrt{1 - \frac{2\omega_p^{\ 2}}{\omega_B^{\ 2}}}\right) \qquad \frac{\omega_p}{\omega_B} << 1$$



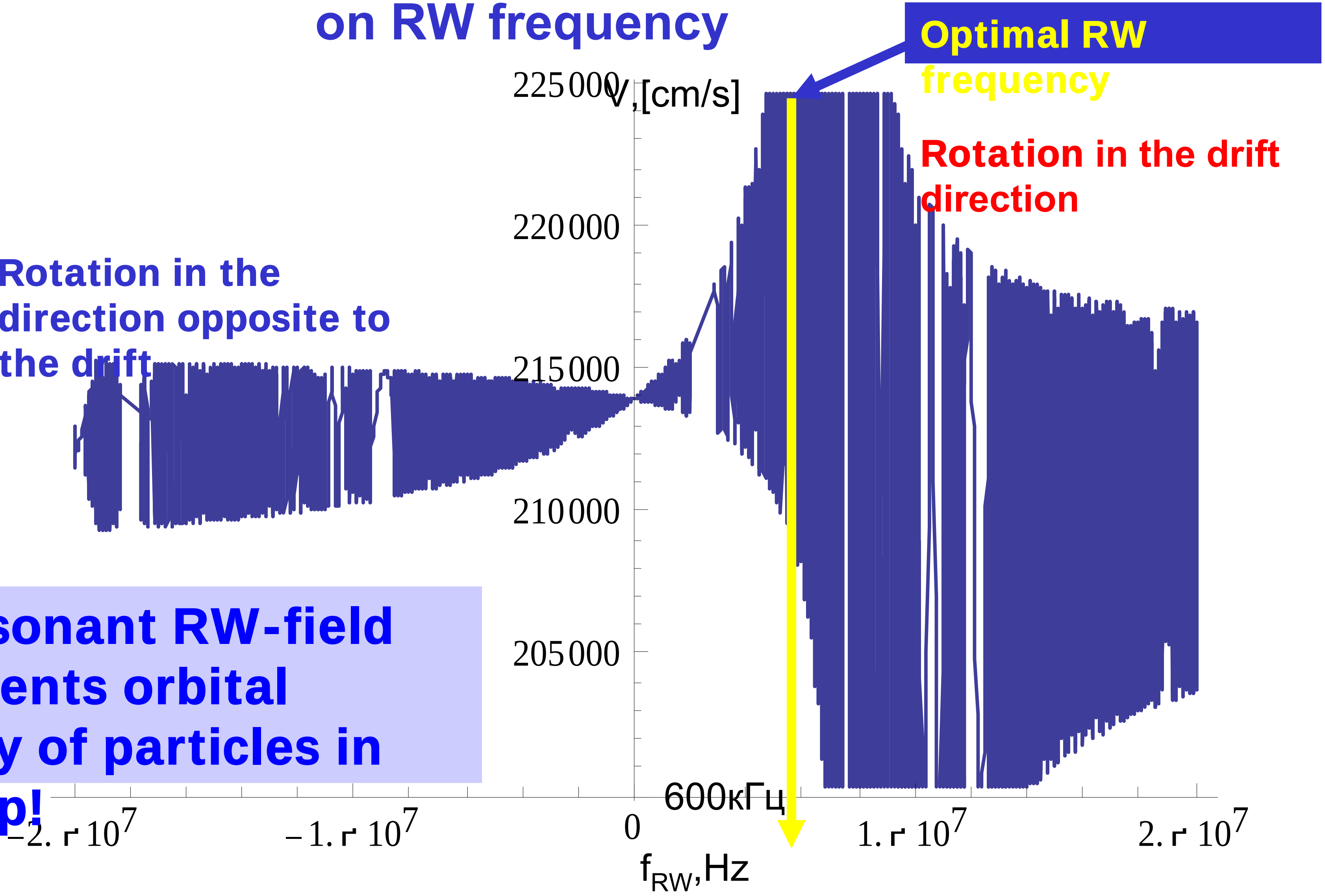
$$\omega^{[1]}{}_{RW} = \frac{\omega_B}{2}\frac{\omega_p^{\ 2}}{\omega_B^{\ 2}} = 2\pi \frac{nec}{B} \qquad \omega^{[2]}{}_{RW} = \omega_B$$

In the solution there is the resonance on frequency of the RW field.

Frequency and direction of rotation of the RW field coincides with frequency and direction of this drift!

$$f_{RW} = f_{drift} = \frac{nec}{B} = 600 \ \text{kHz}$$

Dependence of particle rotation velocity on RW frequency

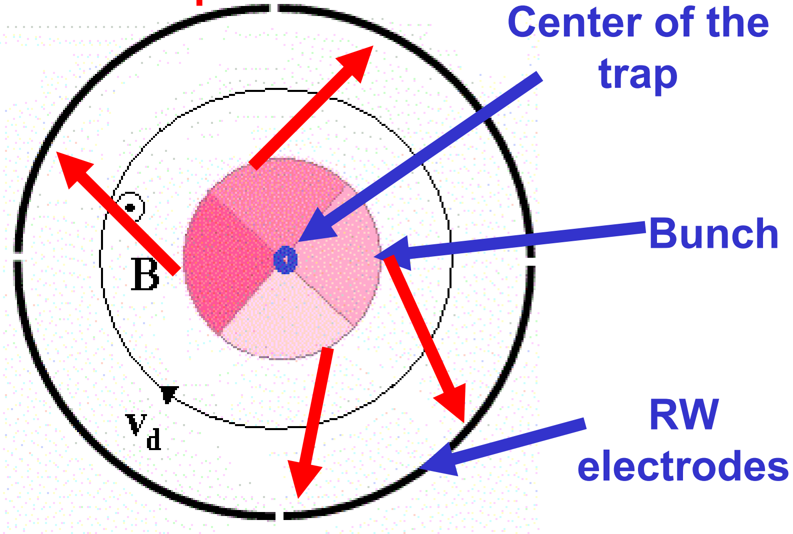


The resonant RW-field increments orbital velocity of particles in the trap!

Numerical simulation of particle motion in the trap

- Particle collective motion, drift in the space charge and B fields
- Gaussian distribution of the particle density
- Longitudinal motion of the particle in the trap
- “The overstep” method

RW off, transverse plan



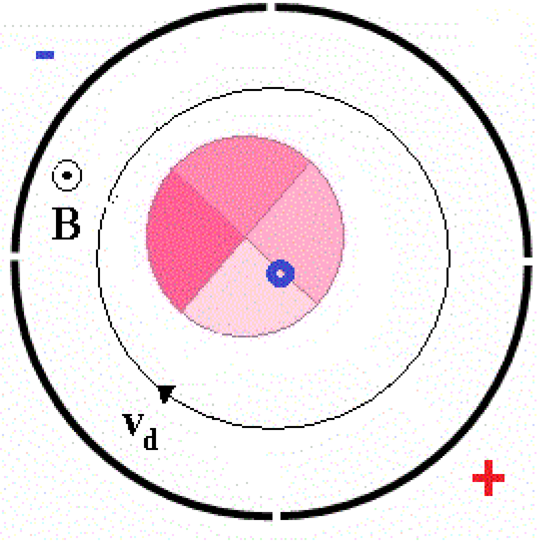
We see positron motion in the crossed B-field and E-field of the bunch space charge.

The orbital drift motion of particles retains them from thermal drift on the trap walls.

But inhomogeneities of the magnetic field and dispersion on residual gas lead to losses of orbital velocity of particles and bunch expansion and decay!

Torque balanced steady states of single component plasmas

RW on, transverse plan



RW rotation in particle drift direction

$$M_\theta^{RW} = \frac{dP_\theta}{dt} = \mathbf{d} \times \mathbf{E}_\omega$$

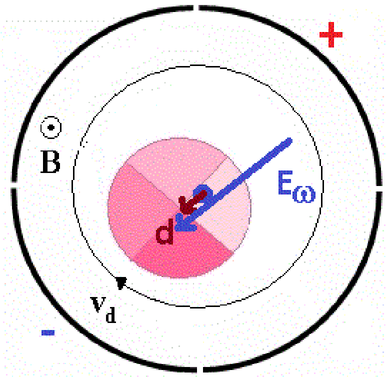
The resonant RW field in addition torque up the bunch.

The bunch has the dipole moment relative trap centre.

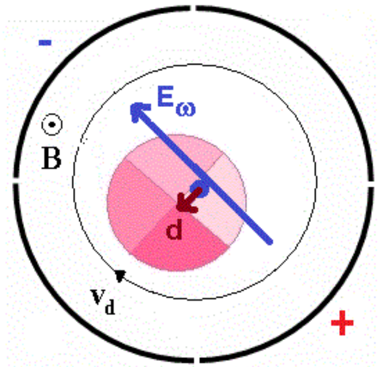
It reduces thermal drift by walls of the trap and increments the lifetime, stability and number of particles storage in the bunch!

The maximum torque is transmitted the bunch in case of perpendicularity of a RW-field and the dipole moment:

M_θ^{RW} is min



M_θ^{RW} is max

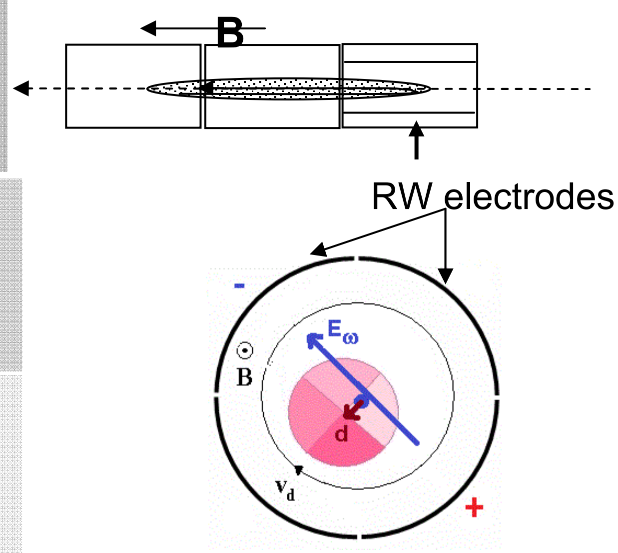


Role of buffer gas and longitudinal motion of particles

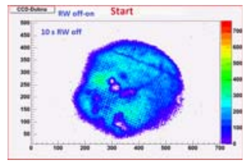
Effect of particle collisions with buffer gas molecules:
energy losses in inelastic collisions. $T_{long} \approx T^{drift}{}_{RW} \approx 1-3 \ \mu s$

Effect segmented electrodes should occupy not all storage region and the scenario particle storage:

- **The longitudinal periodic motion leads to insert of RW field during injection of the particle in RW-electrodes and to cutout its exit of the particle from RW-electrodes.**
- **For magnification of torque of the bunch the moments injection and a particle start in RW-electrodes should be synchronised with orientation of the rotating field.**
- **Therefore RW-electrodes occupy not all storage region and periodicity of the longitudinal motion is compounded with frequency of the rotating field.**



So we manage to explain stabilisation of the bunch and lifetime magnification, but the mechanism of compression of the bunch, observed in experiment, is not clear yet.



4. Methods of positron lifetime increase and bunch compression

The main results:

1. Optimal parameters of the Surko trap at LEPTA have been found:
   - magnetic field value B>1000 G
   - base vacuum ~ 10^{-9} Torr
   - buffer gas pressure in storage region ≈ 10^{-6} Torr,
   - RW amplitude = 0.5 V and frequency ≈ 600 kHz,
   - RW rotation direction along the particle drift;
2. Compression and stabilization of the stored bunch by RW-field application:
   - achievable bunch life time > 100 sec,
   - achievable stored particle number > 10^9 (electrons), 10^7 ? positrons
   - achievable bunch transverse size < 1 cm;
3. Bunch intensity increase by the controlled storage regime:
   - dynamic magnification of frequency of the RW field and depth of the potential well with growth of number of the storage up particles.

5. Nearest plans

Basic vacuum in the trap is critical parameter at positron accumulation

The annihilation rate $\lambda = \pi r_0^2 c Z_{eff} n$

He Z_{eff}=4, H_2 Z_{eff}=14.6
N_2 Z_{eff}=30, O_2 Z_{eff}=36
$C_{10}H_8$ Z_{eff}=1240000

G. F. Gribakin, J. A. Young , C. M. Surko // Review of modern physics. 2010, Vol. 82 – P. 2257.

Plans of the new experiments with the Surko trap

1) Storage of positrons in the Surko trap and extraction of monochromatic bunch for positron annihilation spectroscopy (transfer channel is under design)
2) Transverse e^+ bunch profile measurement with CCD camera;
3) Positron injection into LEPTA storage ring and positronium generation.

$e^+ + e^- =$ **oPs** / **pPs**

Summary and Outlook

1. **“The Rotating Wall” method was studied experimentally at LEPTA injector and a high efficiency of particle storage with RW application has been obtained**
2. **Optimal Surko trap parameters have been found**
3. **It was found that the RW mechanisms were discussed at the LEPTA Trap parameters**
4. **Methods of optimization of the particle storage and bunch compression in the Surko trap has been obtained**
5. **First experimental results of positron storage in the LEPTA trap have been presented**

Thank you for attention!