THE TWO-STREAM TRANSVERSE INSTABILITY & BEAM PERFORMANCE LIMITATION

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Two-stream instability

- Beam interaction with elements of accelerator and secondary plasma can be the reason for instabilities, causing limited beam performance.
- Improving of vacuum chamber design and reducing of impedance by orders of magnitude relative with earlier accelerators increases threshold intensity for impedance instability.
- Two-stream effects (beam interaction with a secondary plasma) become a new limitation on the beam intensity and brightness. Electron and Antiproton beams are perturbed by accumulated positive ions. Proton and positron beams may be affected by electrons or negative ions generated by the beam. These secondary particles can induce very fast and strong instabilities. These instabilities become more severe in accelerators and storage rings operating with high current and small bunch spacing

Scope of the 13th ICFA Beam Dynamics Workshop

Instability and beam induced pressure rise include electron stimulated gas desorption, ion desorption, and beam loss/halo scraping. Beam induced pressure rise had limited beam intensity in CERN ISR and LEAR. Currently, it is a limiting factor in RHIC, AGS Booster, and GSI SIS. It is a relevant issue at SPS, LANL PSR, and B-factories. For projects under construction and planning, such as SNS, LHC, LEIR, GSI upgrade, and heavy ion inertial fusion, it is also of concern.

Invited Talks (eclouds’03)

- F. Ruggiero - LHC Concerns
- J. Wei - SNS Concerns
- W. Fischer - RHIC Concerns
- A. Molvik - HIF (Heavy Ion Fusion) Concerns
- O. Boine-Frankenheim - GSI Upgrade
- M. Chanel - LHC Heavy Ion Injectors
- J.M. Jimenez - SPS Issues
- R. Macek - PSR Issues
- S.Y. Zhang - AGS Booster Issues
- A. Kraemer - SIS Experiments
- E. Mahner - LINAC3 Measurement Results
- P. Chiggiato - NEG Coating
- U. Wienands - PEP-II Vacuum Experience
- Y. Suetsugu - KEKB Observations
- E. Mustafin - Vacuum Instability

Scope of ECLOUD'04

- The existence of electron cloud effects (ECEs), which include vacuum pressure rise, emittance growth, instabilities, heat load on cryogenic walls and interference with certain beam diagnostics, have been firmly established at several storage rings, including the PF, BEPC, KEK-B, PEP-II, SPS, PSR, APS and RHIC, and is a primary concern for future machines that use intense beams such as linear collider damping rings, B factory upgrades, heavy-ion fusion drivers, spallation neutron sources and the LHC.

Budker Institute of Nuclear Physics

www.inp.nsk.su

First project of proton/antiproton collider VAPP, in the Novosibirsk INP (BINP), 1960

- Development of charge-exchange injection (and negative ion sources) for high brightness proton beam production. First observation of e-p instability.
- Development of Proton/ Antiproton convertor.
- Development of electron cooling for high brightness antiproton beam production.
- Production of space charge neutralized proton beam with intensity above space charge limit. Inductance Linac, Inertial Fusion, Neutron Generators.

References

www.google.com two-stream transverse instability…

For more information see the website for the

8th ICFA Mini Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, Santa Fe, NM Feb 16-18, 2000

http://www.aps.anl.gov/conferences/icfa/two-stream.html

Also see the website for the

International Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, KEK Tsukuba, Japan, Sept 11-14, 2001

http://conference.kek.jp/two-stream/

http://wwwslap.cern.ch/collective/electron-cloud/.

Two-stream instability, historical remarks

- Beam instability due to electrons were first observed with coasting proton beam or long proton bunches at the Novosibirsk INP(1965), the CERN ISR(1971), and the Los Alamos PSR(1986). SNS performance can be affected by e-p instability.
- Recently two-stream instability was observed in almost all storage rings with high beam intensity.
- Observation of two-stream instability in different conditions will be reviewed. Beam performance limitation, diagnostics and damping of two-stream instability will be discussed

Historical remark

Electron cloud effects (ECEs) were first observed 38 yrs ago in small, medium-energy proton storage rings. These were described as: Vacuum pressure bump instability, beam-induced multipacting, and/or e-p instability:

BINP Proton Storage Ring [G. Budker, G. Dimov, and V. Dudnikov (1966); see also review by V. Dudnikov (2001)] v.dudnikov.ph.D.thesis,1966

CERN Intersecting Storage Ring (ISR) [O. Grobner (1977)]

First observation in a positron ring around 1995: Transverse coupled-bunch instability in e+ ring only and not in e- ring:

KEK Photon Factory (PF) [M. Izawa, Y. Sato, T. Toyomasu (1995) and K. Ohmi, (1995)]

IHEP Beijing e+/e- collider (BEPC): experiments repeated and KEK PF results verified [Z.Y. Guo et al. (1997)]

Models of two-stream instability

- The beam- induces electron cloud buildup and development of two-stream e-p instability is one of major concern for all projects with high beam intensity and brightness [1,2].
- In the discussing models of e-p instability, transverse beam oscillations is excited by relative coherent oscillation of beam particles (protons, ions, electrons) and compensating particles (electrons,ions) [3,4,5].
- For instability a bounce frequency of electron's oscillation in potential of proton's beam should be close to any mode of betatron frequency of beam in the laboratory frame.

1. http://wwwslap.cern.ch/collective/electron-cloud/.

2. http://conference.kek.jp/two-stream/.

3. G.I.Budker, Sov.Atomic Energy, 5,9,(1956).

4. B.V. Chirikov, Sov.Atomic.Energy,19(3),239,(1965).

5. M.Giovannozzi, E.Metral, G.Metral, G.Rumolo,and F. Zimmerman , Phys.Rev. ST-Accel. Beams,**6**,010101,(2003).

References for first observation of e-p instability

- V.Dudnikov, Ph.D.Thesis, The intense proton beam accumulation in storage ring by charge-exchange injection method”, Novosibirsk INP,1966.
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- G.I.Dimov, V.G.Dudnikov,” Transverse instability of a proton beam due to coherent interaction with a plasma in a circular accelerator” Soviet Conference on Charge- particle accelerators”,Moscow,1968, translation from Russia, 1 1973 108565 8.
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Development of Charge Exchange Injection and Production of Circulating Beam with Intensity Greater than Space Charge Limit

V.Dudnikov. "Production of an intense proton beam in storage ring by a charge- exchange injection method", Novosibirsk, Ph.D.Thesis,INP, 1966.
Development of a Charge- Exchange Injection; Accumulation of proton beam up to space charge limit; Observation and damping of synchrotron oscillation; Observation and damping of the coherent transverse instability of the bunched beam. Observation of the e-p instability of coasting beam in storage ring
G. Budker, G. Dimov, V. Dudnikov, "Experiments on production of intense proton beam by charge exchange injection method" in Proceedings of International Symposium on Electron and Positron Storage Ring, France,Sakley,1966, rep. VIII, 6.1 (1966).
G. Budker, G. Dimov, V. Dudnikov, "Experimental investigation of the intense proton beam accumulation in storage ring by charge- exchange injection method", Soviet Atomic Energy, 22, 384 (1967).
G.Dimov, V.Dudnikov, "Determination of circulating proton current and current density distribution (residual gas ionization profile monotor)", Instrum. Experimental Techniques, 5, 15 (1967).
Dimov. "Charge- exchange injection of protons into accelerators and storage rings", Novosibirsk, INP, 1968.
Development of a Charge- Exchange Injection; Accumulation of a proton beam up to the space charge limit; Observation and damping of synchrotron oscillations; Observation and damping of the coherent transverse instability of the bunched beam;.
Shamovsky. "Investigation of the Interaction of the circulating proton beam with a residual gas", Novosibirsk, INP, 1972.
Observation of transverse e-p coherent instability of the coasting beam in the storage ring, Observation of a transverse Herward's instability, Damping of instabilities, Accumulation of a proton beam with a space charge limit.
G. Dimov, V. Dudnikov, V. Shamovsky, "Transverse instability of the proton beam induced by coherent interaction with plasma in cyclic accelerators", Trudy Vsesousnogo soveschaniya po uskoritelyam, Moskva, 1968, v. 2, 258 (1969).
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Chupriyanov. "Production of intense compensated proton beam in an accelerating ring", Novosibirsk, INP, 1982.
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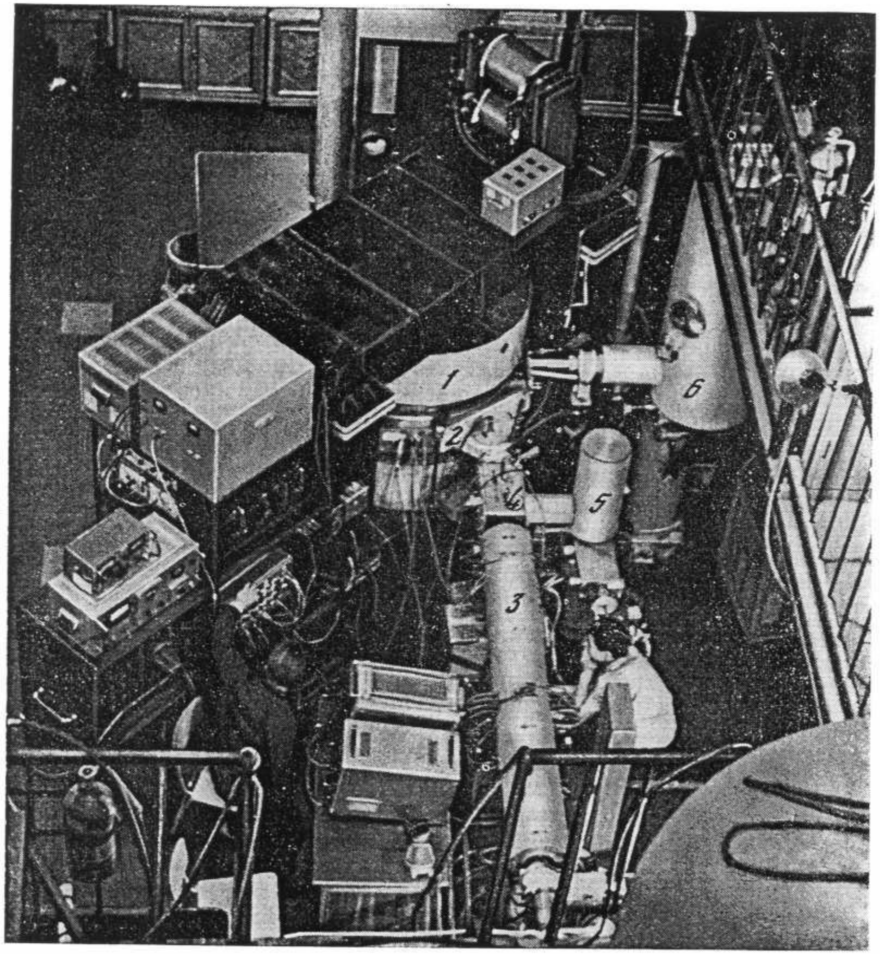
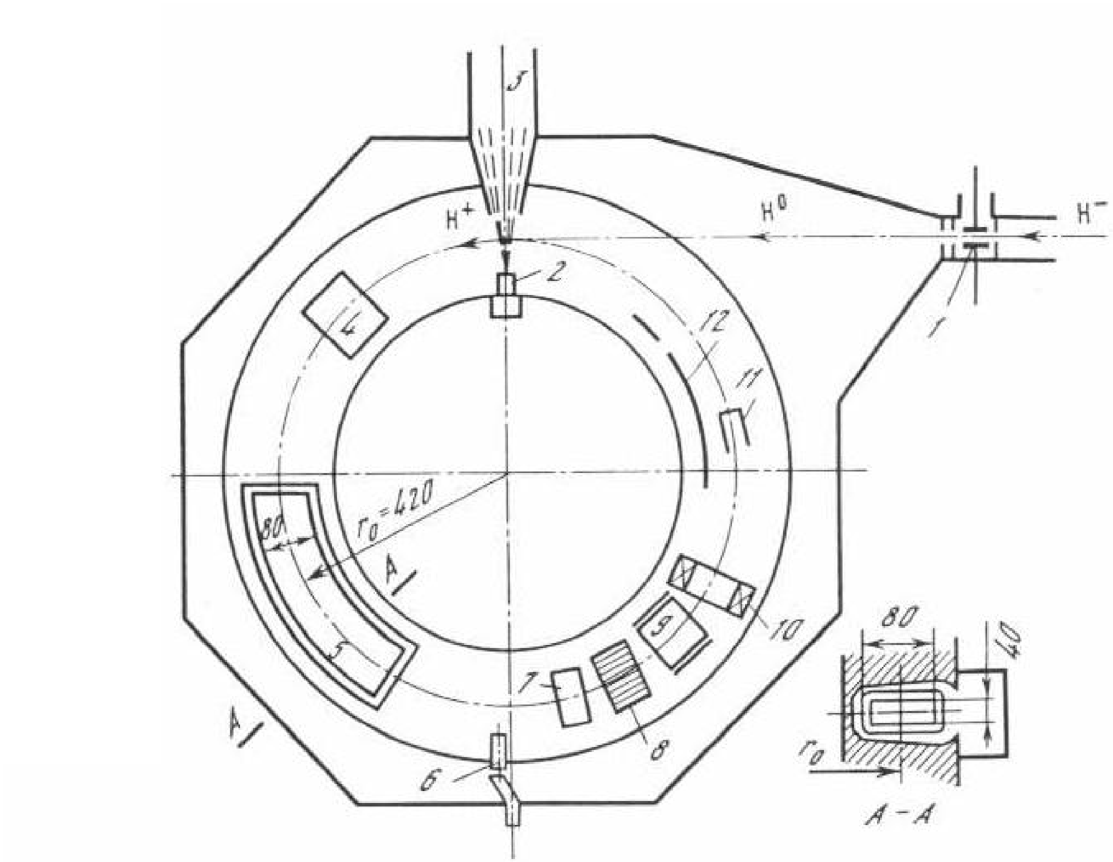
Particle accelerators, 14, 155- 184 (1984). Yu.Belchenko, G.Budker, G.Dimov, V.Dudnikov, et al.X PAC,1977.

General view of INP PSR with charge exchange injection 1965



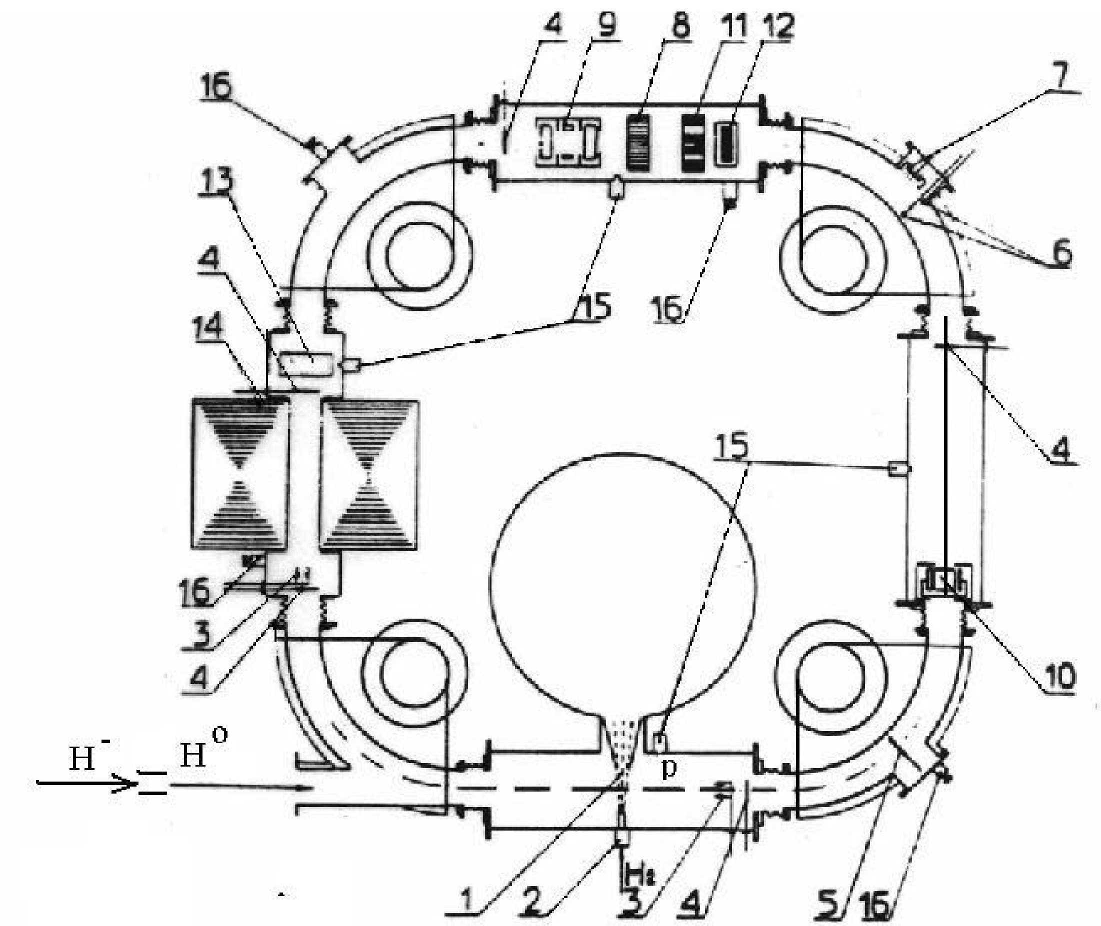
PSR for bunched beam accumulation by charge exchange injection



1- Fist stripper; 2-main stripper Pulsed supersonic jet; 3-gas pumping;
4-pickup integral;
5- accelerating drift tube;
6-gas luminescent profile Monitor; 7-Residual gas current monitor;8-residual gas IPM; 9-BPM;
10-transformer Current monitor; 11-FC;
12- deflector for Suppression transverse instability by negative Feedback.

Small Radius- High beam density

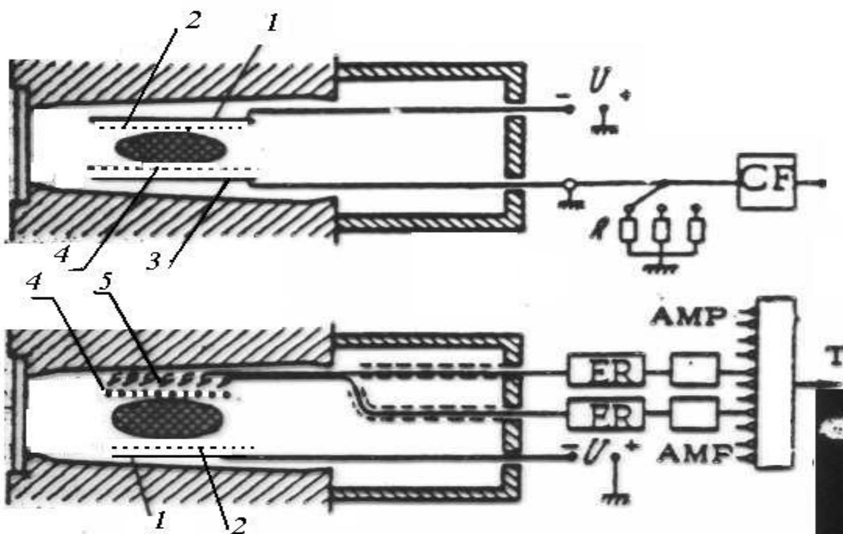
PSR for Circulating p-Beam Production

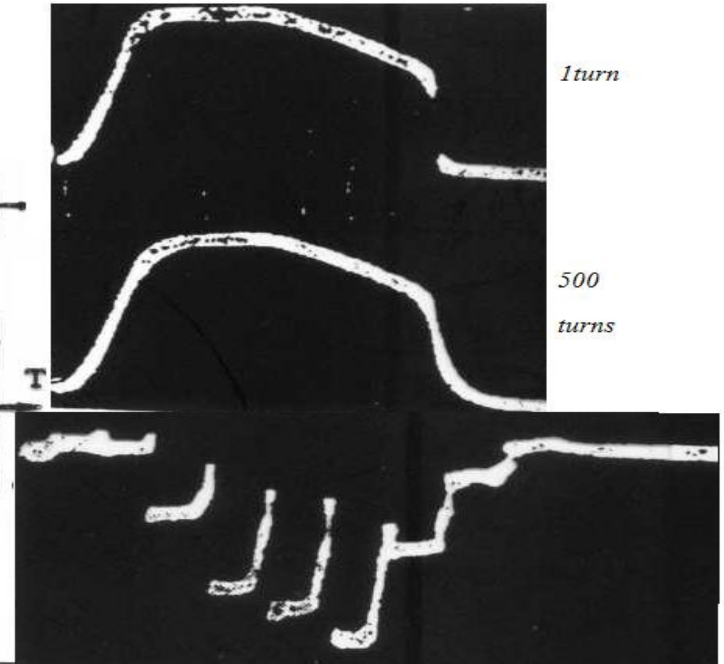


1-striping gas target; 2-gas pulser;3-FC; 4-Q screen; 5,6-moving targets; 7-ion collectors; 8-current monitor; 9-BPM;10-Q pick ups; 11-magnetic BPM; 12-beam loss monitor;13-detector of secondary particles density; 14-inductor core; 15-gas pulsers; 16-gas leaks.

Proton Energy -1 MeV; injection-up to 8 mA; bending radius-42 cm; magnetic field-3.5 kG;index-n=0.2-0.7; St. sections-106 cm;aperture-4x6 cm; revolution-1.86 MHz; circulating current up to 300mA is up to 9 time greater than a space charge limit.

Residual gas ionization beam current & profile monitor ans secondary particles detector

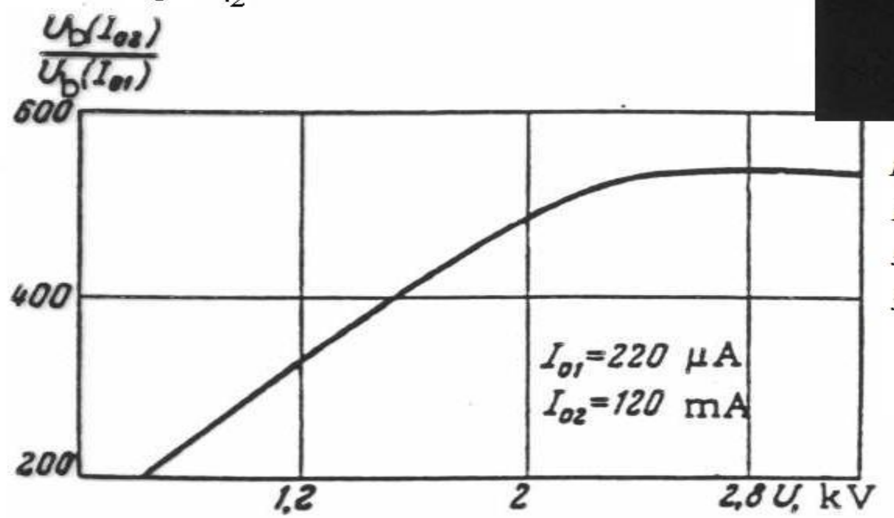




1turn

500

turns



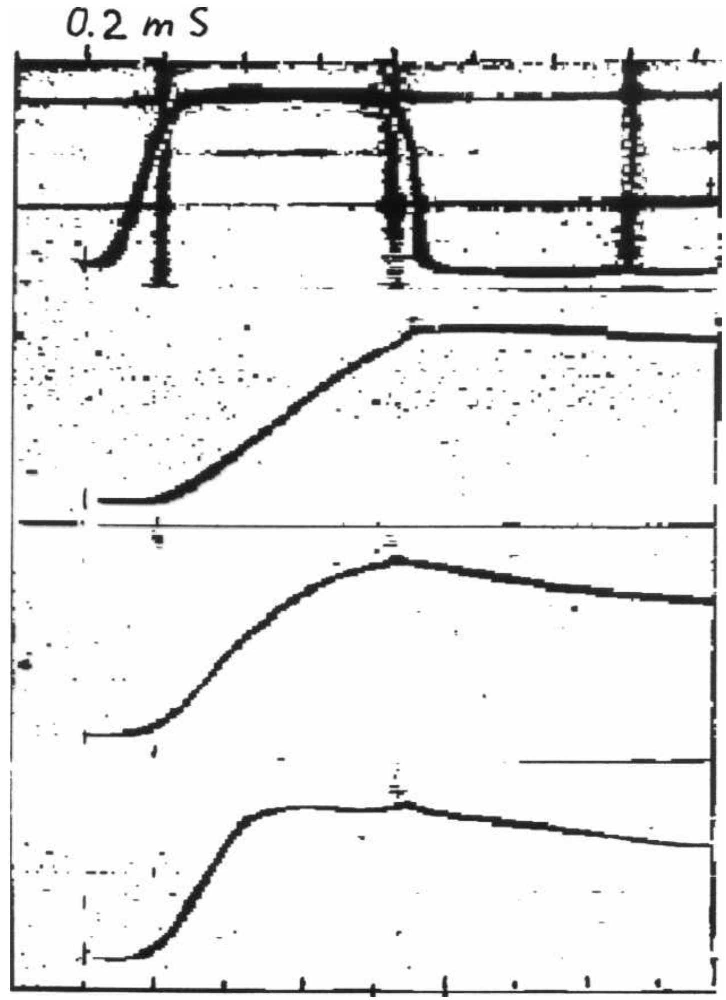
Residual gas IPM.V.Dudnikov,1965.

1-reflection platre;2-suppression grid;

3-collector plate;4-shilding grid;

5 collector strips.

Proton beam accumulation for different injection current (0.1-0.5 mA)



Injected beam

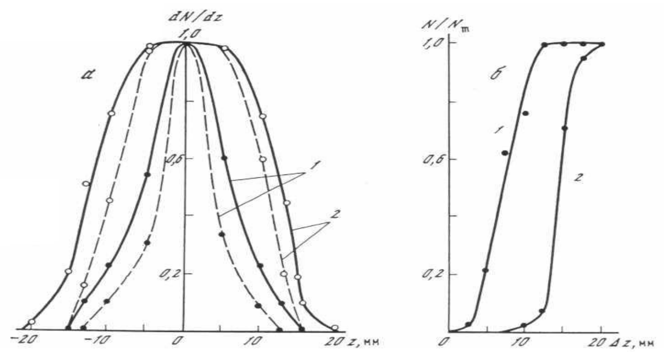
Circulating beam,

Low injection current

Start saturation

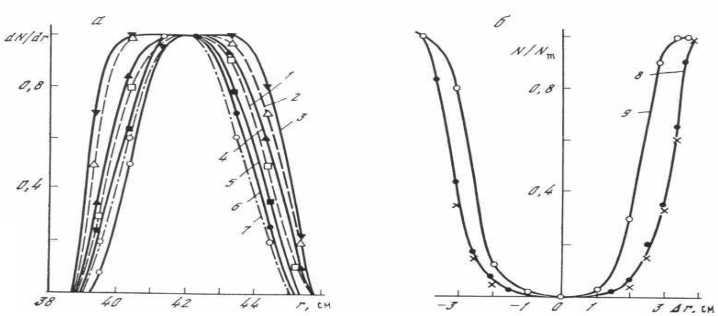
Strong saturation

Beam profiles evolution during accumulation



Residual gas luminescent beam profilometer signa, and beam intensity vs vertical aperture

a — $N_m = 2 \cdot 10^{11}$; б — $N_m = (2 \div 20) \cdot 10^{10}$; 1 — $\alpha_z = 0$; 2 — $\alpha_z = 0{,}12$



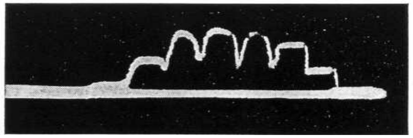
Residual gas ionization beam profile monitor (IPM) signal and beam intensity vs radial aperture

1 — 6: $N_m = 2{,}5 \cdot 10^{11}$, $t = 1600$ мкс (1); 900(2); 700(3); 400(4); 200(5); 50(6); 7 — $N_m = 5 \cdot 10^{10}$, $t = 200 \div 2000$ мкс; 8 — $N_m = 2{,}6 \cdot 10^{11}$; 9 — $5 \cdot 10^{10}$

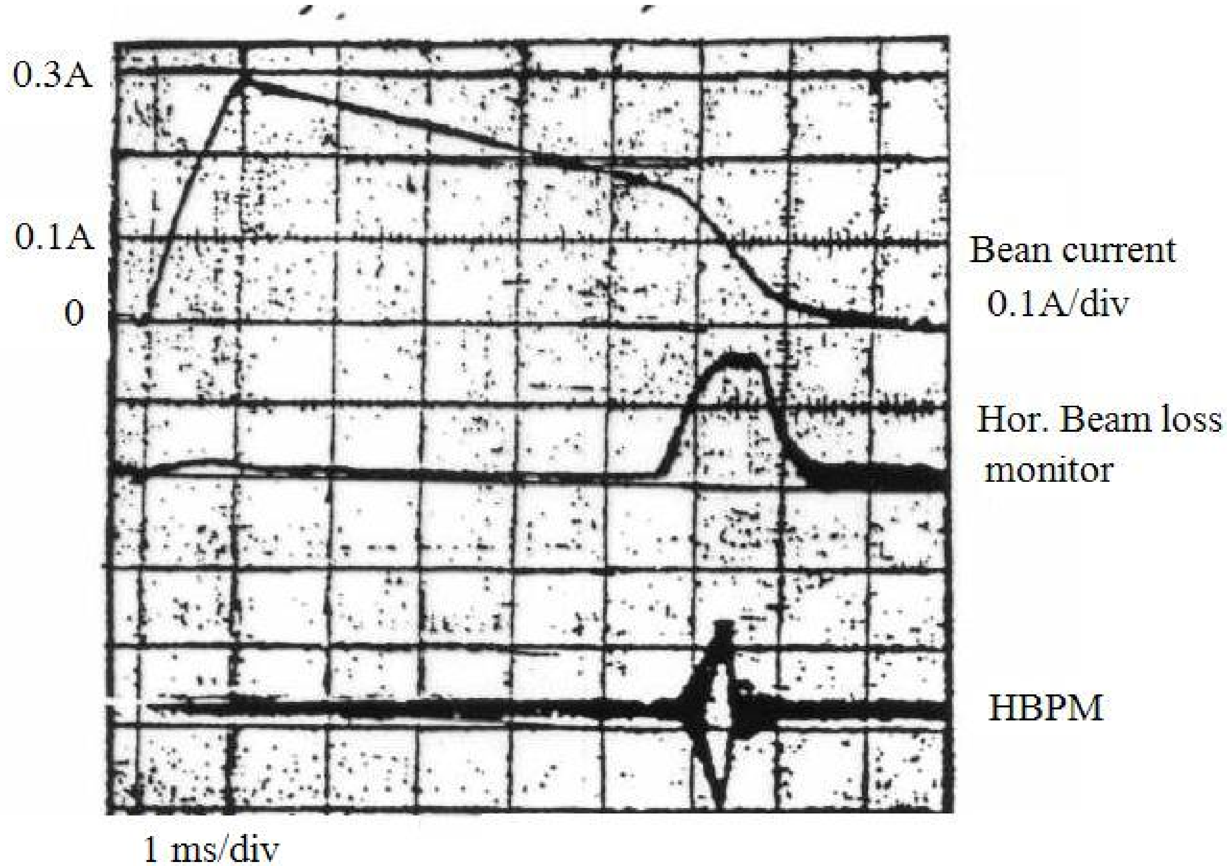
IPM signal, electron collection in B field

Step 9mm.

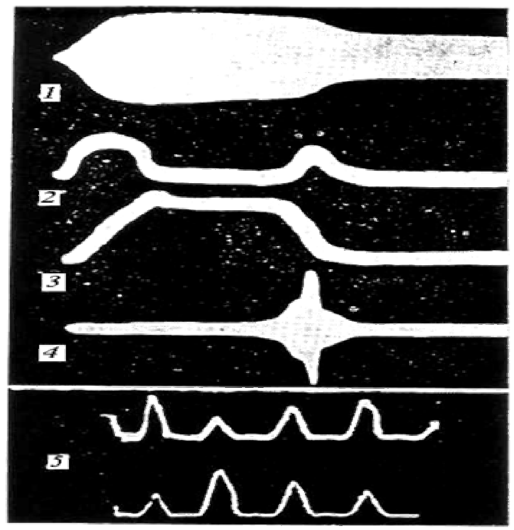
V.Dudnikov, 1965,

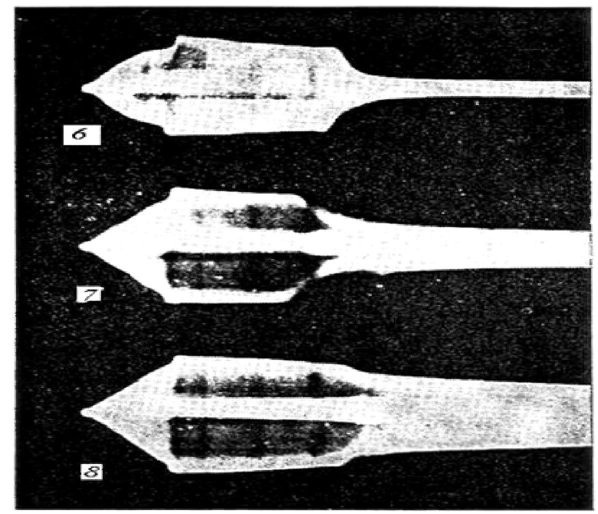


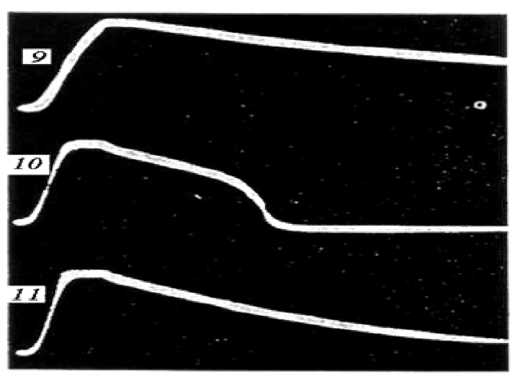
Transverse instability in the INP PSR, bunched beam (1965)



Transverse instability of bunched beam in INP PSR (1965)



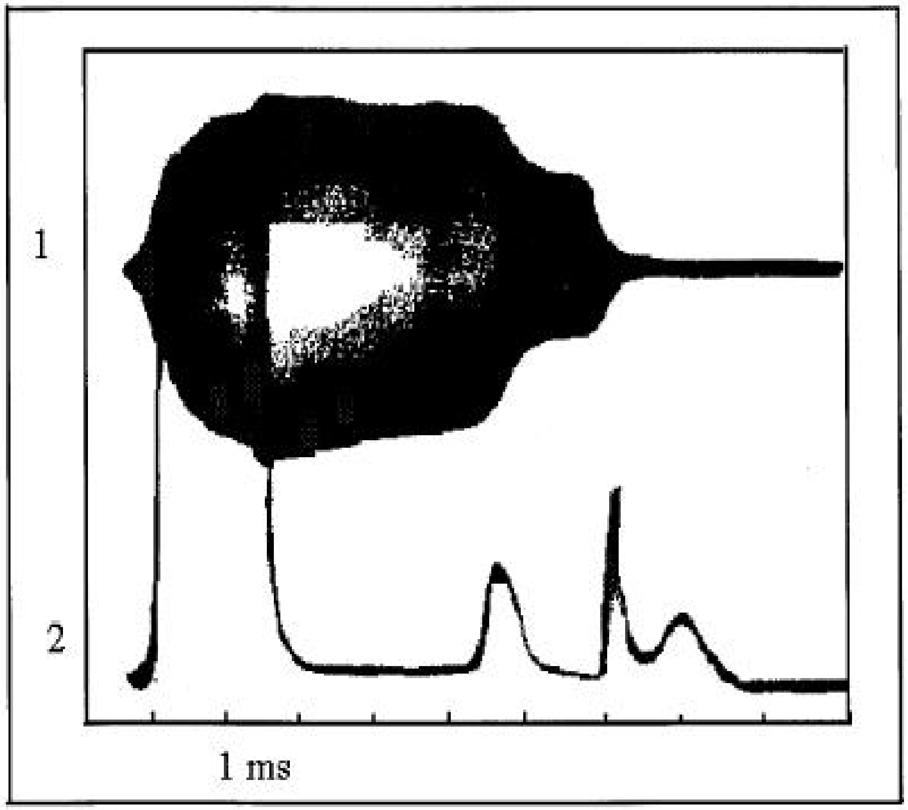




Transverse e-p instability in INP Proton storage ring (PSR), 1965. *bunched beam*   *Injection time is 1ms*

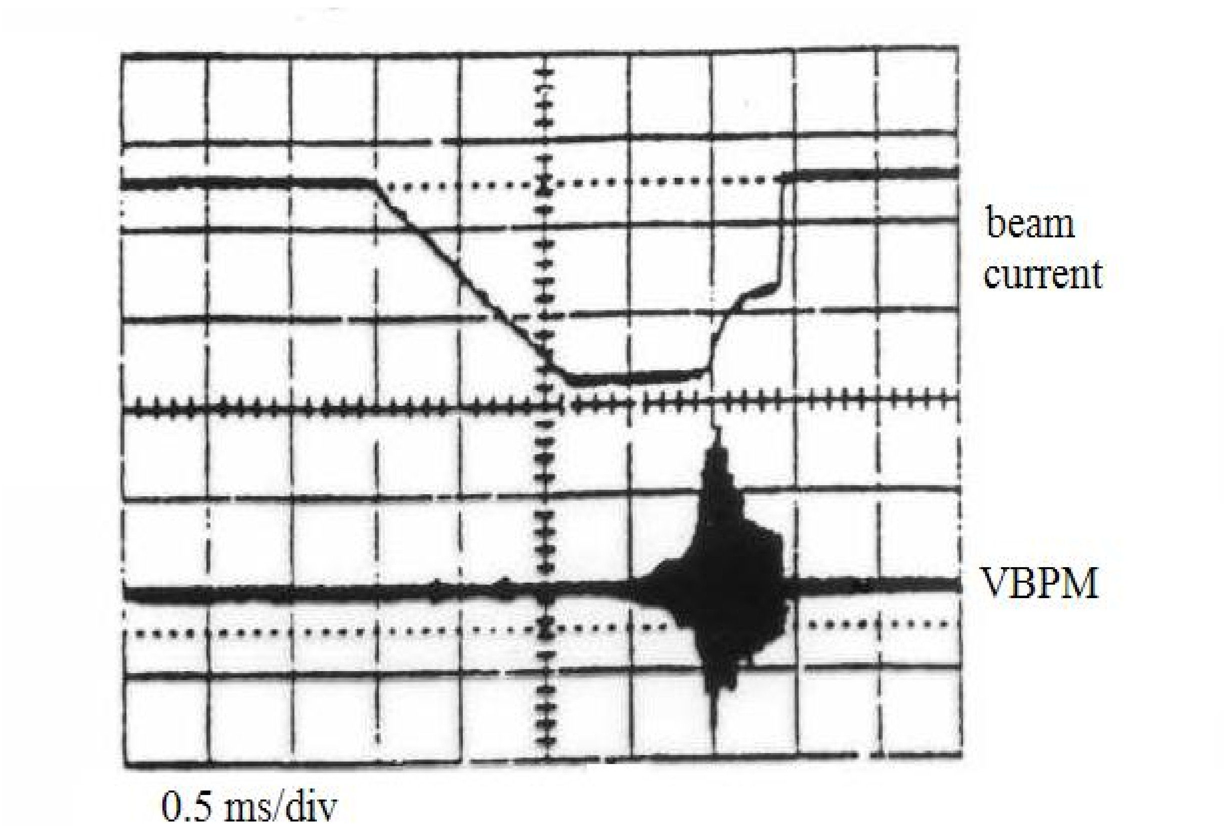
1-pick up electrode signal; 2-beam loss monitor;
3-beam intensity; 4-Rad.BPM; 5-radial pick ups;
6-pick up signal Urf=1.4kV; 7-pick up signal Urf=2.8;
8-pick up signal Urf=4.2kV;
9- beam intensity below threshold for instab;
10-beam intensity above threshold for instability, no fied back stabilization; 11- beam intensity above threshold for transverse instability, fied back stabilization ON.

Transverse instability of bunched beam with a high RF voltage



1-ring pickup, peak bunch intensity ;
2-radial loss monitor.
Beam was deflected after Instability loss.
Two peaks structure of beam after instability loss.
Only central part of the beam was lost

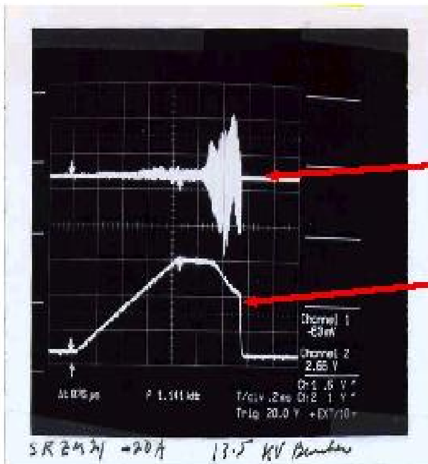
Transverse instability in Los Alamos PSR, bunched beam (1986)



e-p instability in LA PSR, bunched beam

Well Established ep Instability Characteristics at PSR

Instability Signals

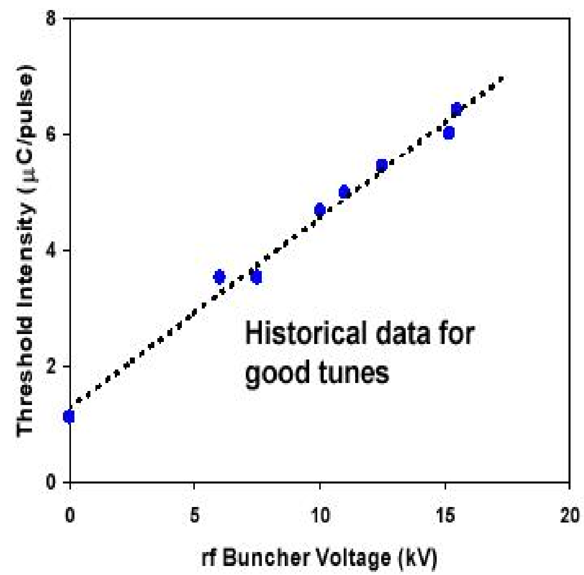


BPM ΔV signal

CM42 (4.2 μC) (Circulating Beam Current)

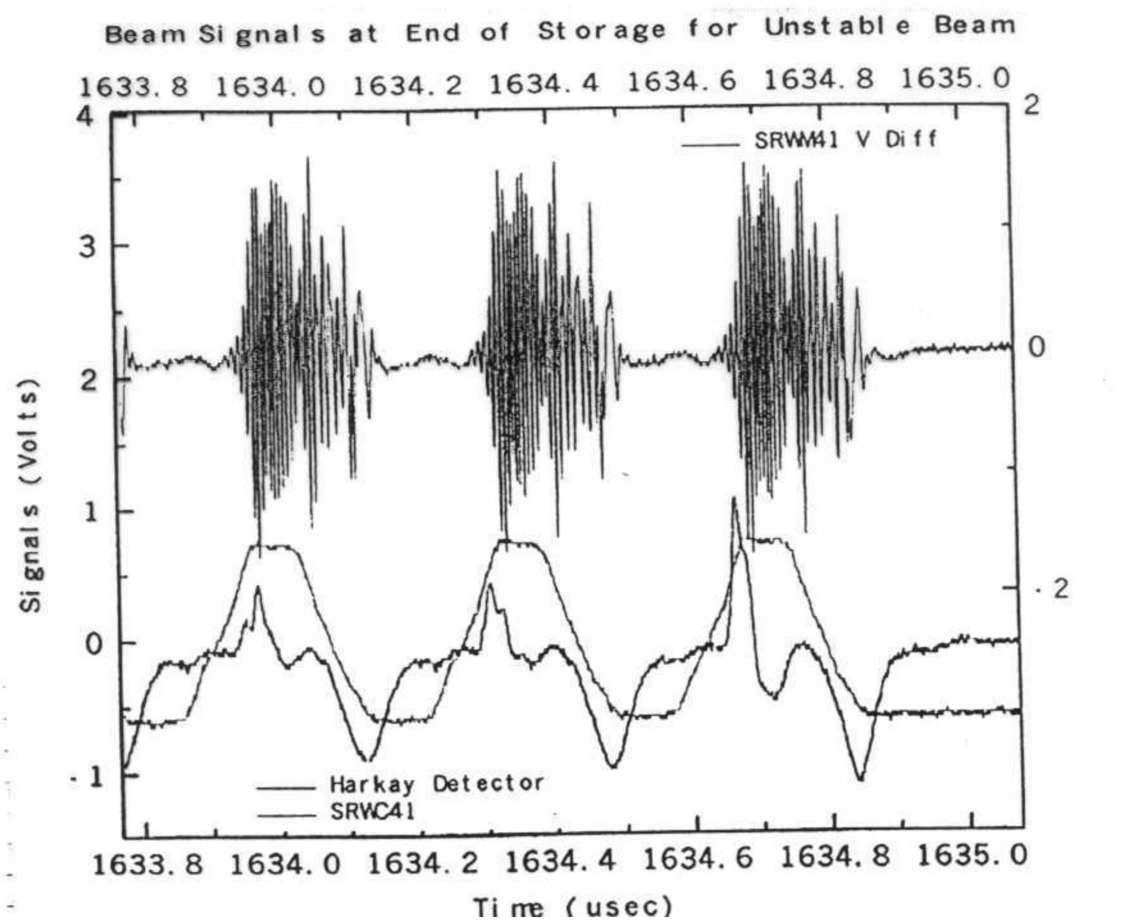
- Growth time ~ 75 μs or ~200 turns
- High frequency ~ 70 – 200 MHz
- Controlled primarily by rf buncher voltage
- Requires electron neutralization of ~ 1% (from centroid model)

Control by rf buncher voltage

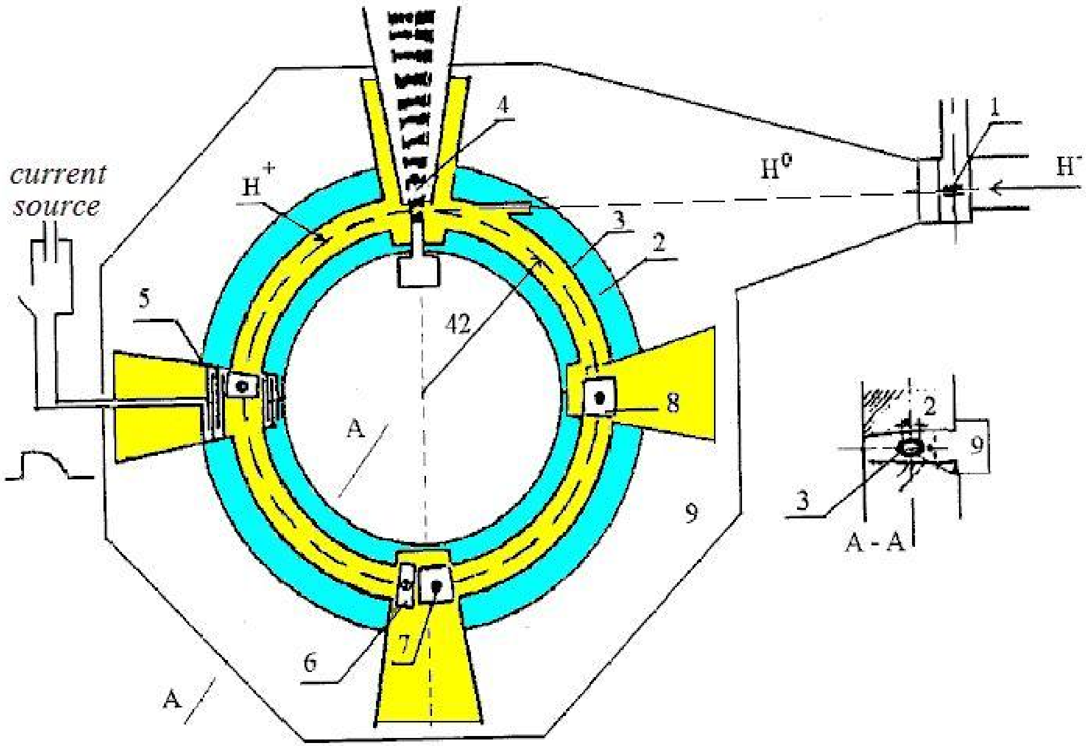


Macek, LANL

Pickup signals and electron current in LA PSR

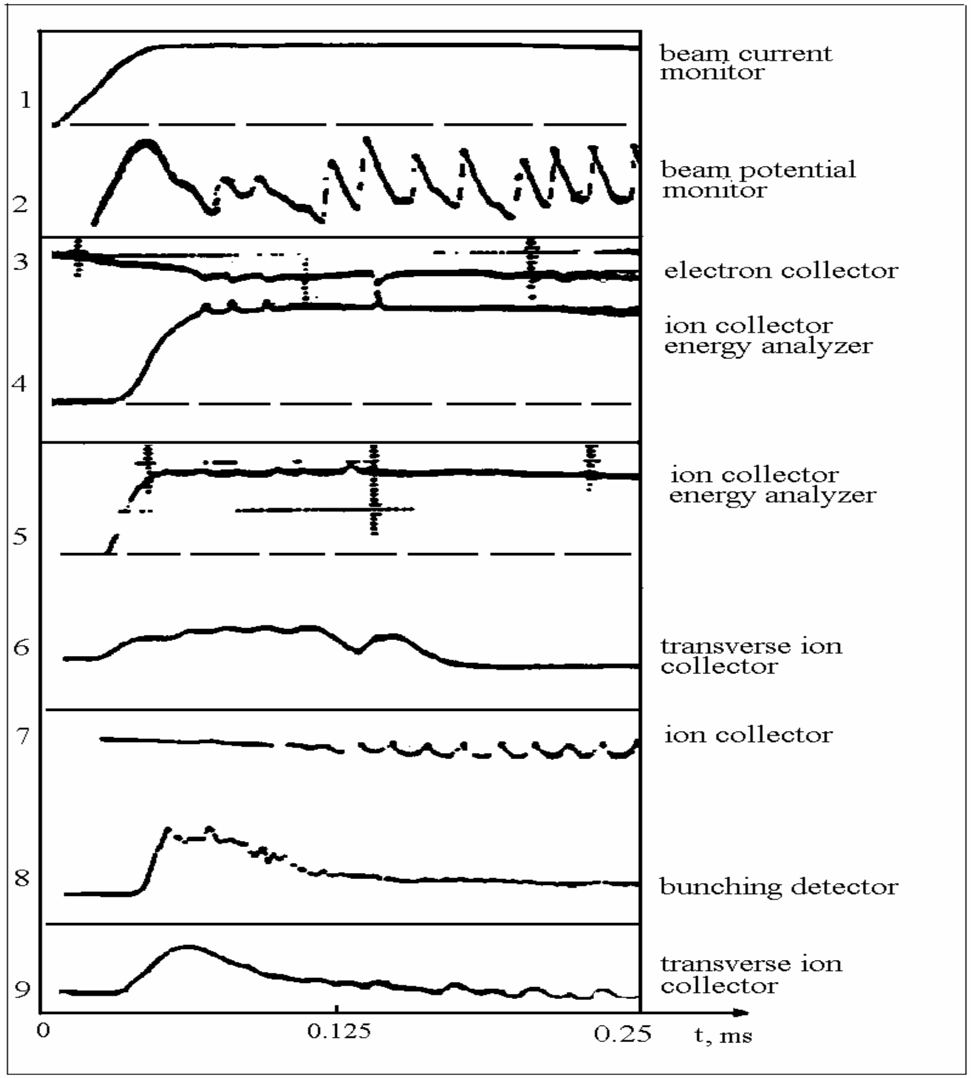


PSR for beam accumulation with inductance acceleration



1-first stripper;
2-magnet pole n=0.6;
3-hollow copper torus
with inductance current;
4-main stripper;
5-accelerating gap;
6-ring pickup; 7-BPMs;
8-Res.gas IPM;
9-vacuum chamber.
FC; quartz screens;
Retarding electron and
ion collectors/
spectrometers .

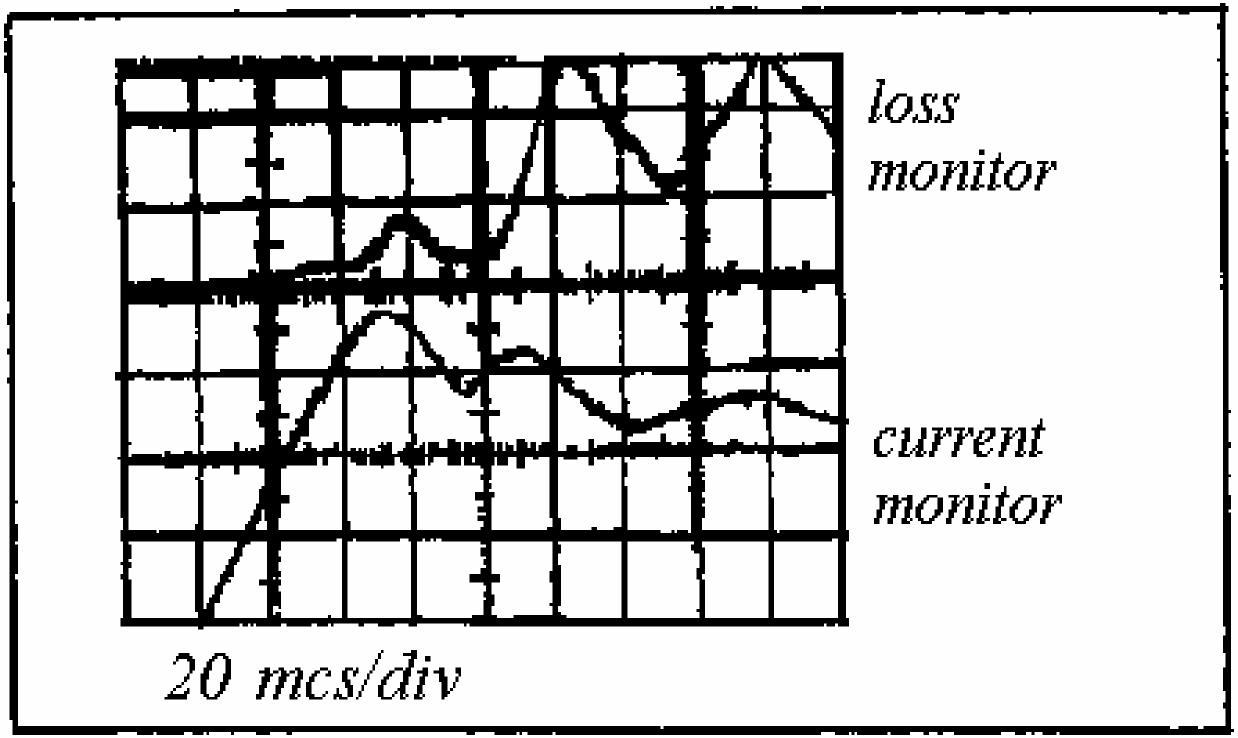
e-p instability with a low threshold in INP PSR



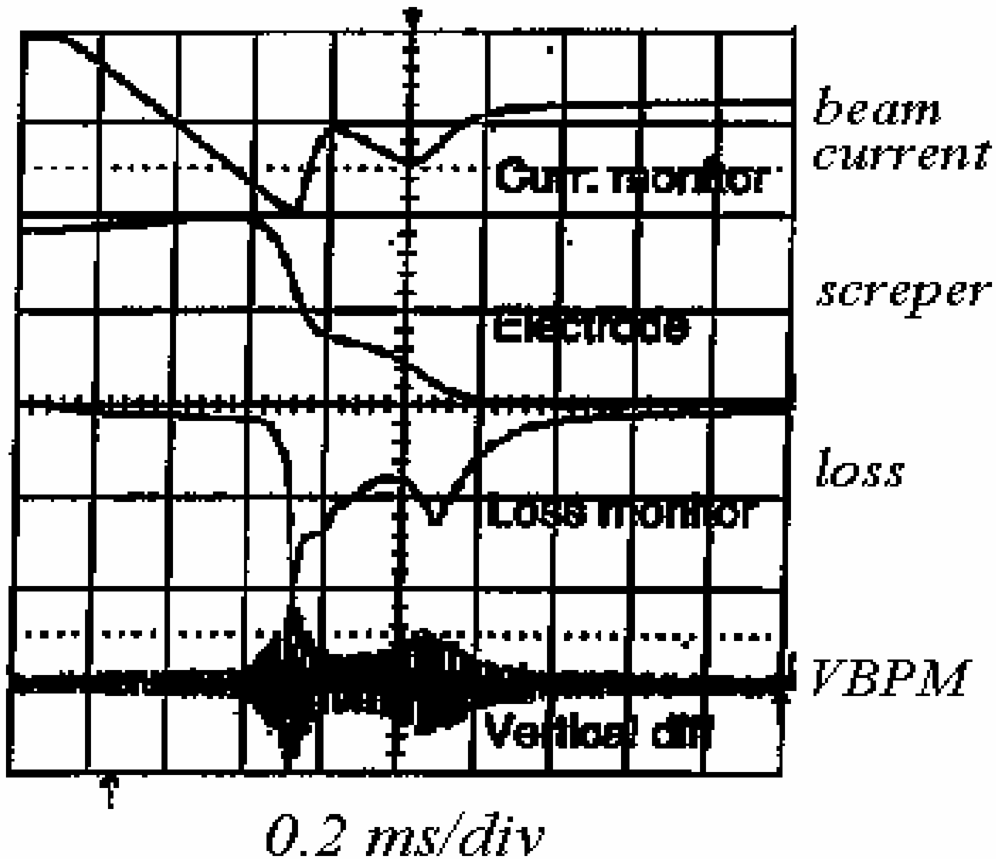
1-beam current, N>7e9p
2-beam potential, slow
Accumulation of electrons
10mcs, and fast loss 1mcs.
3-retarding electron collector;
4,5-ion collector, ionizing
Current Monitor;
6,7-ion Collectors Beam
potential monitor;
8,9- negative mass Instability.

Injection:
Coasting beam, 1MeV, 0.1mA
R=42 cm.

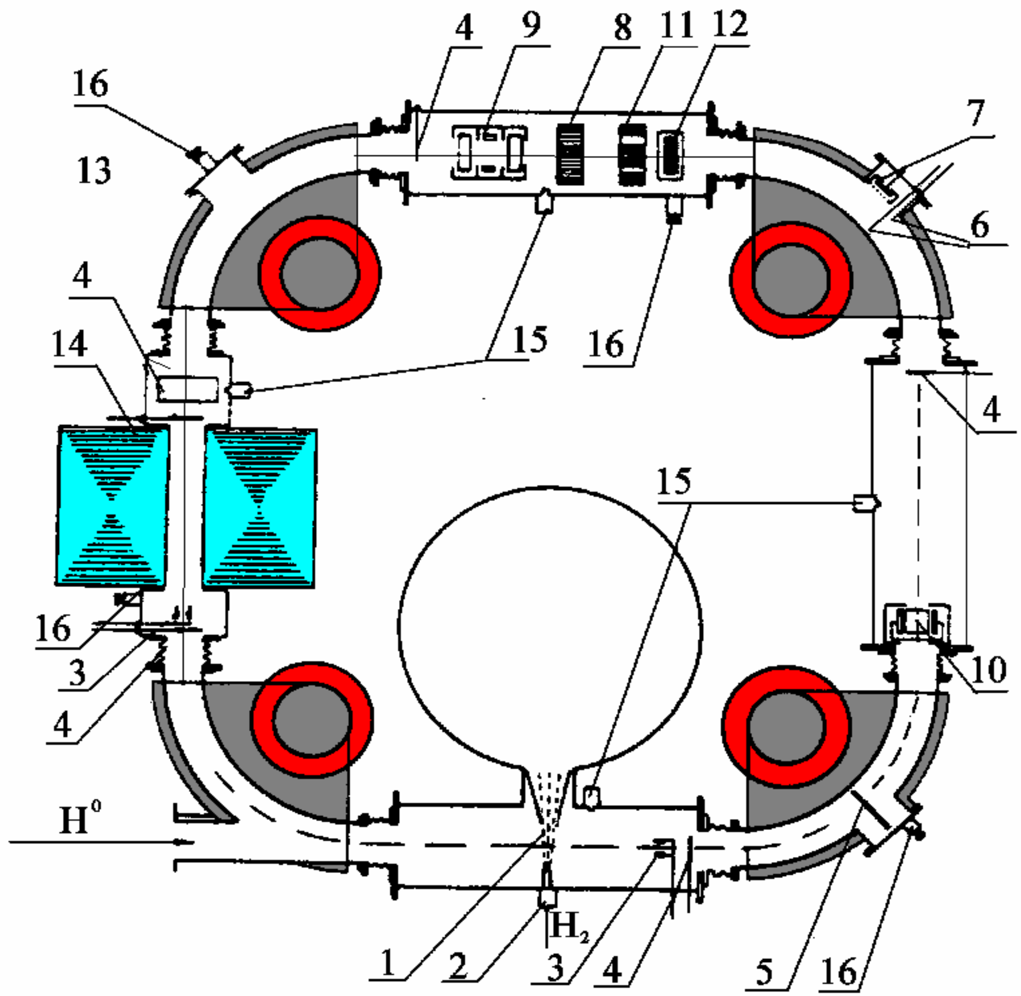
e-p instability of coasting beam in the INP PSR (1967)



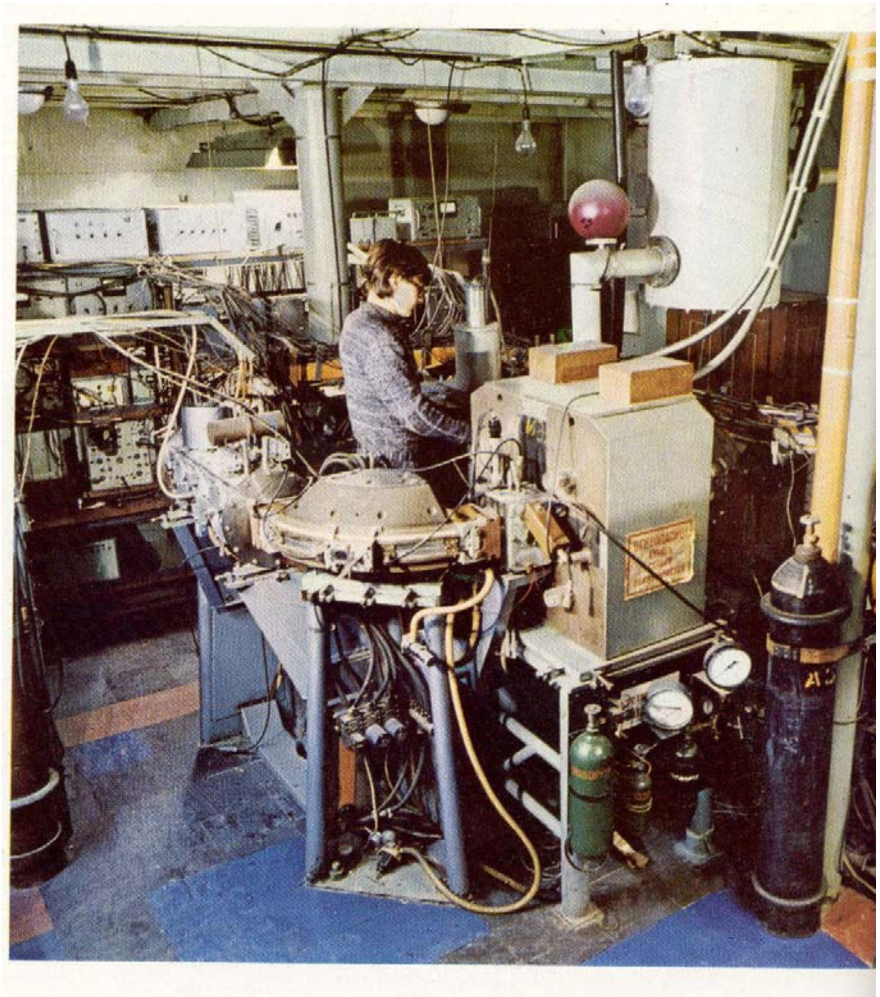
e-p instability of coasting beam in LA PSR,1986



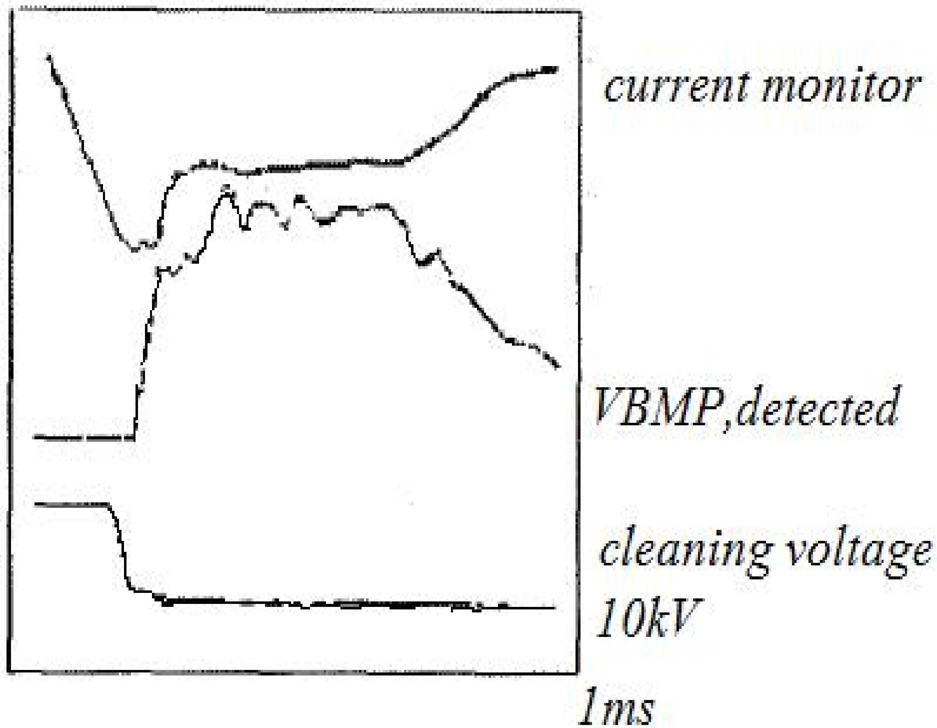
INP PSR for beam above space charge limit



Small Scale Proton Storage Ring for Accumulation of Proton Beam with Intensity Greater than Space Charge Limit

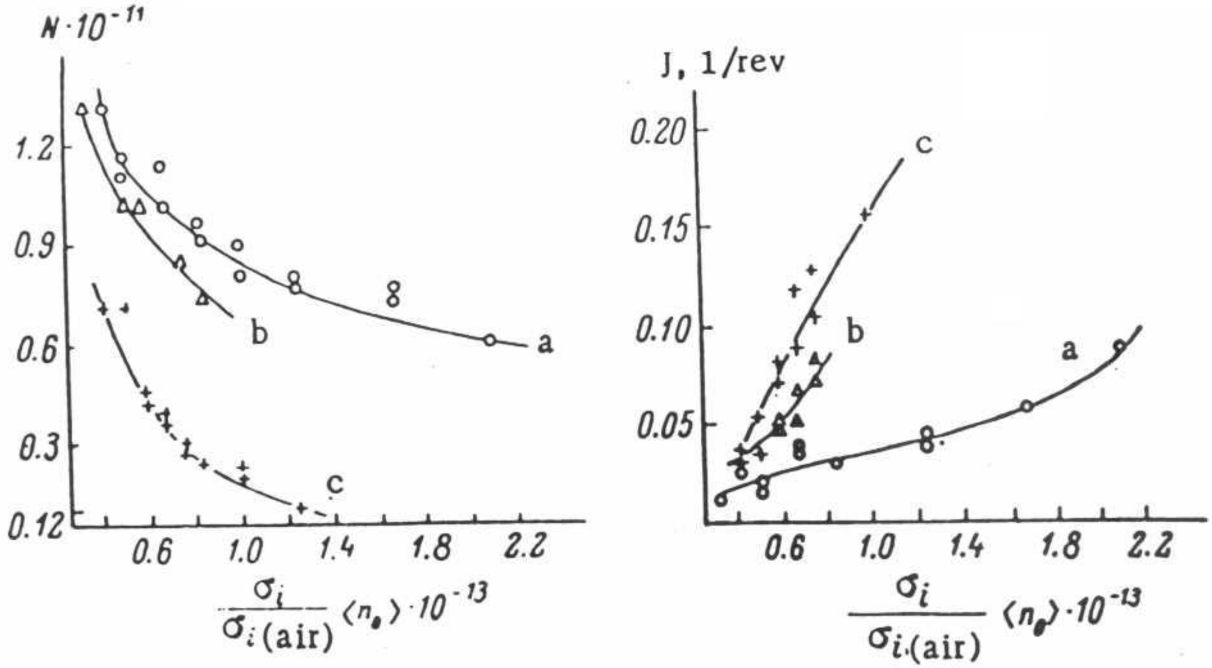


Beam accumulation with clearing voltage



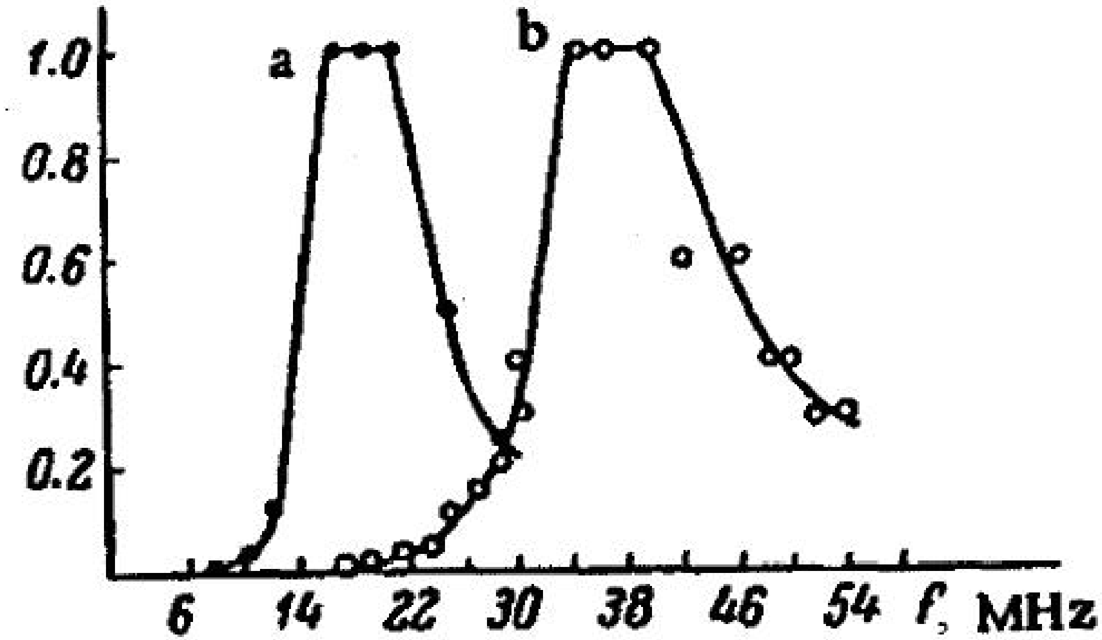
Secondary plasma accumulation suppressed by strong transverse electric field. Vertical instability with zero mode oscillation was observed (Herward instability).

Threshold intensity N (left) and growth rate J (right) of instability as function of gas density n



a-hydrogen; b-helium; c-air.

Spectrums of coasting beam instability in BINP PSR (magnetic BPM)

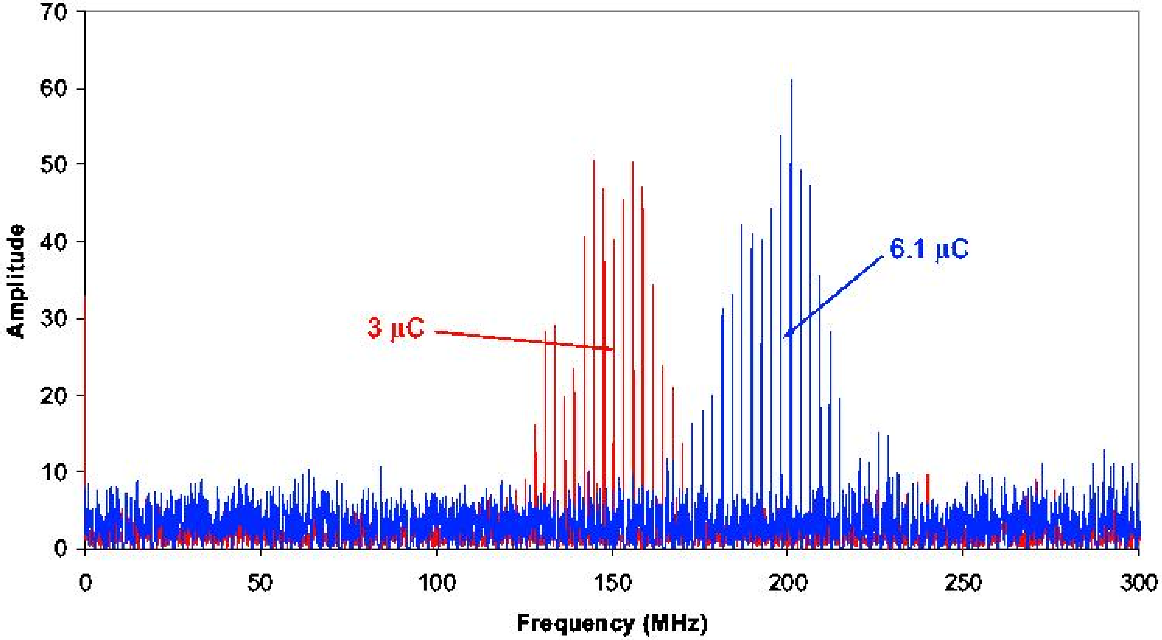


Spectrum of signals from vertical beam position monitor.
a) $N=1.7\ 10^{10}$ p; b) $N=1.5\ 10^{11}$ p.

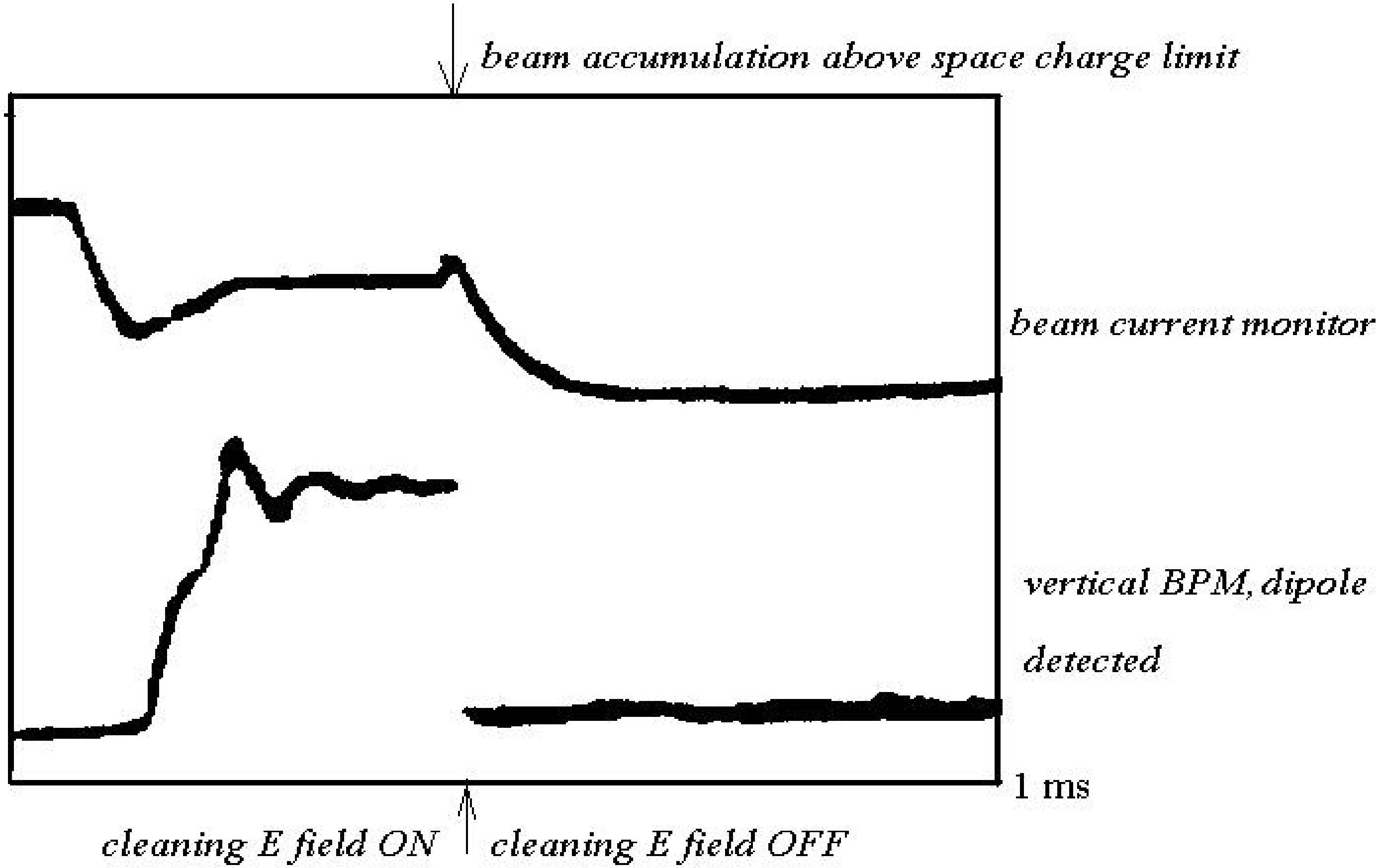
Spectrums transverse beam instability in LA PSR

Frequency spectra of unstable motion agrees with model

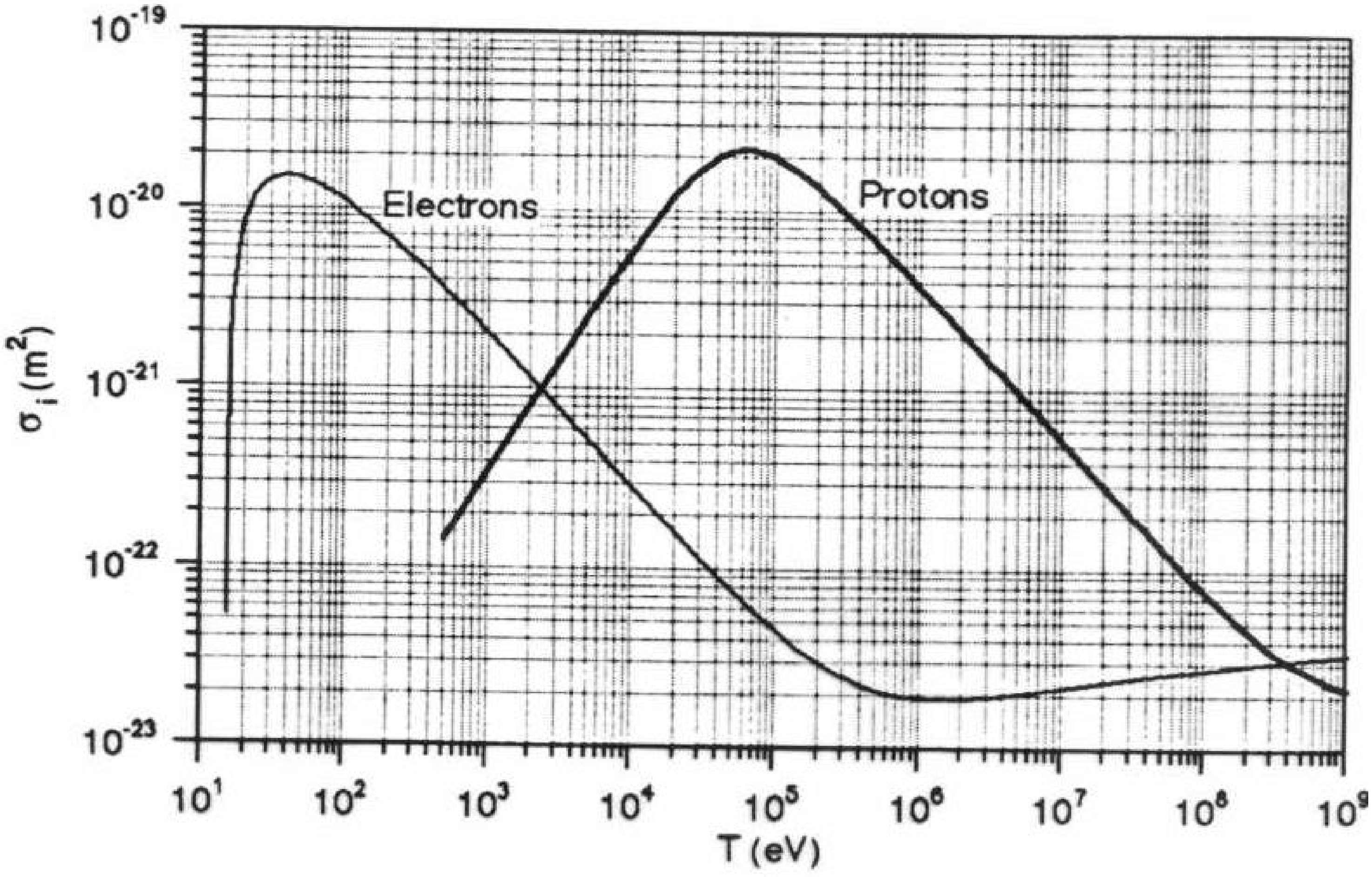
$$\omega_e = Q_e\Omega_0 = 2\pi f = \sqrt{\frac{2Nr_e c^2(1-f_e)}{\pi b(a+b)R}}, \qquad f \approx 230\ \mathrm{MHz}\ (6.1\mu C)$$



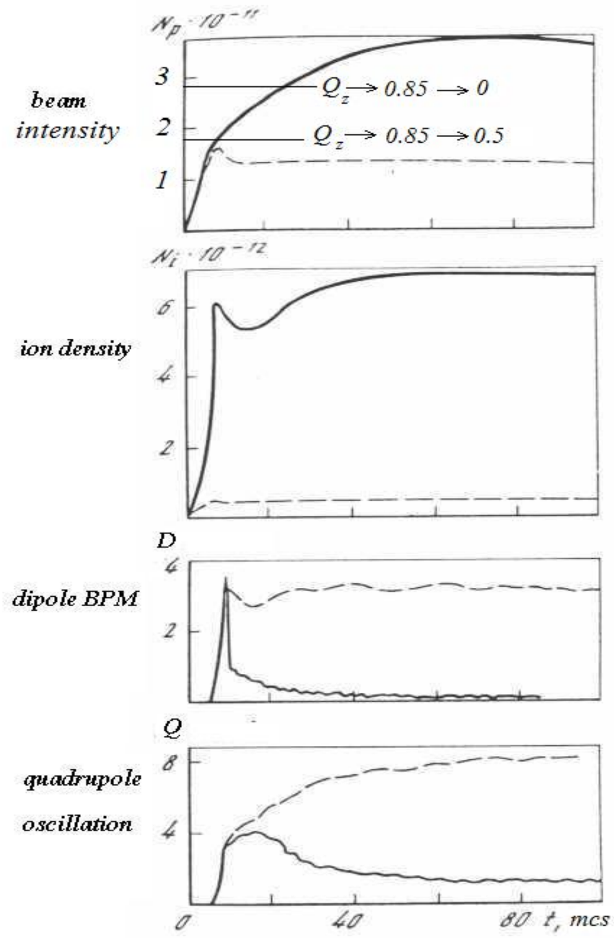
Beam accumulation with space charge neutralization

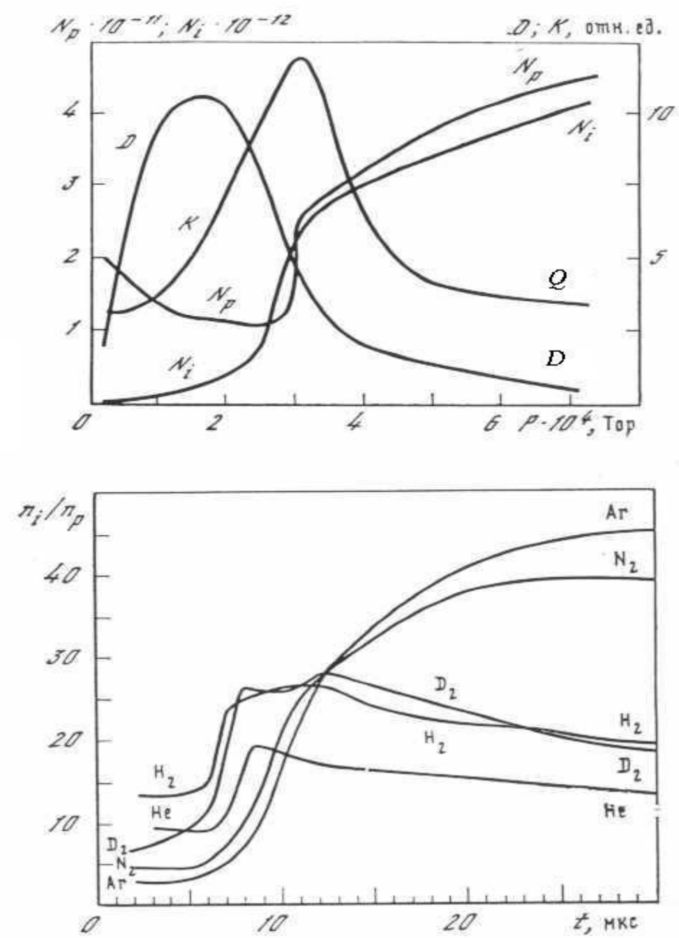


Ionization cross sections for H

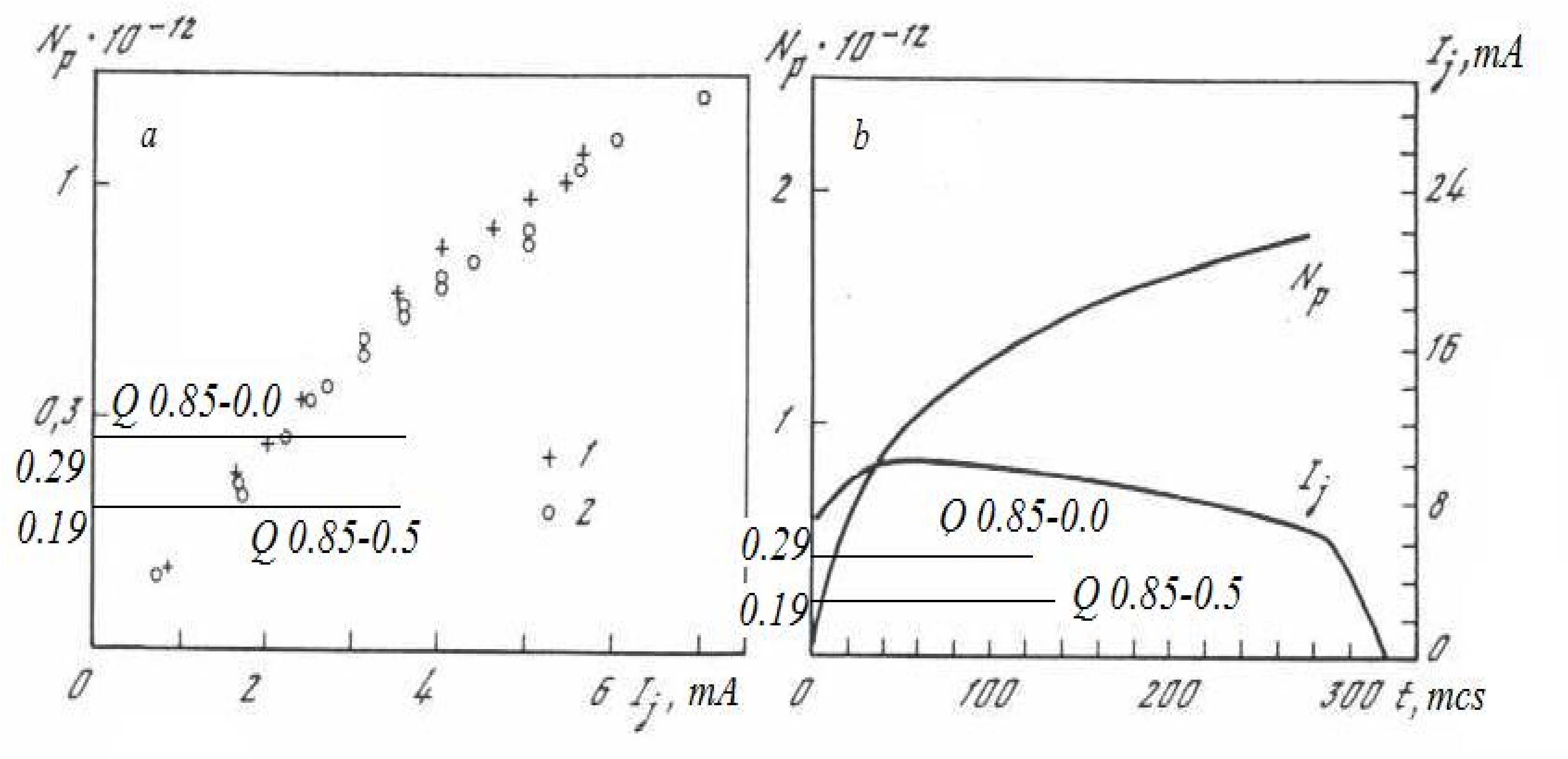


Proton beam accumulation with intensity above space charge limit



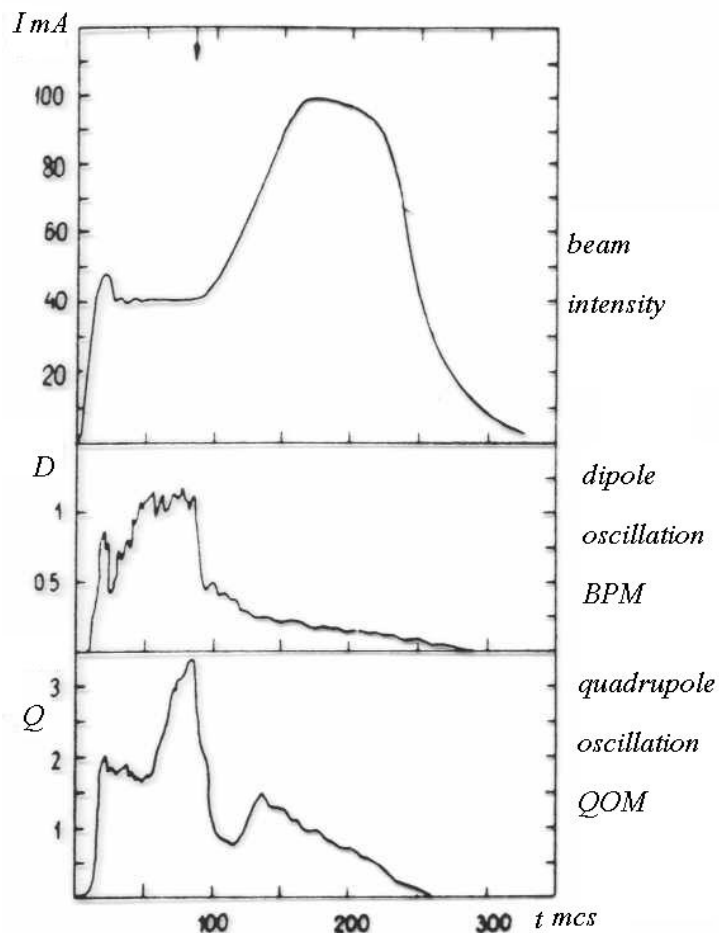


Proton beam accumulation with intensity grater than space charge limit. Dependence of injection current.



Beam accumulation with a plasma generator

on



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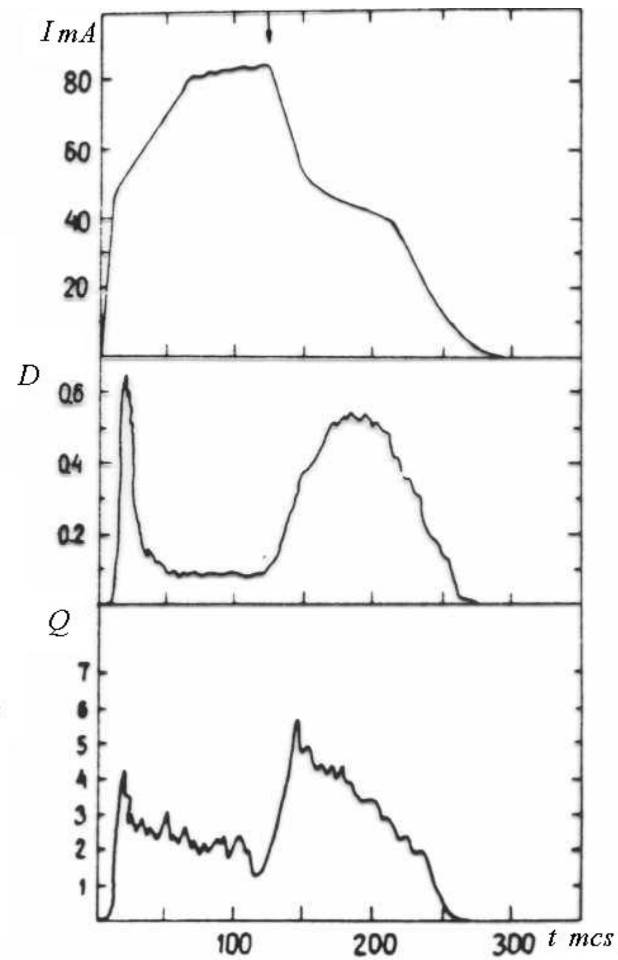
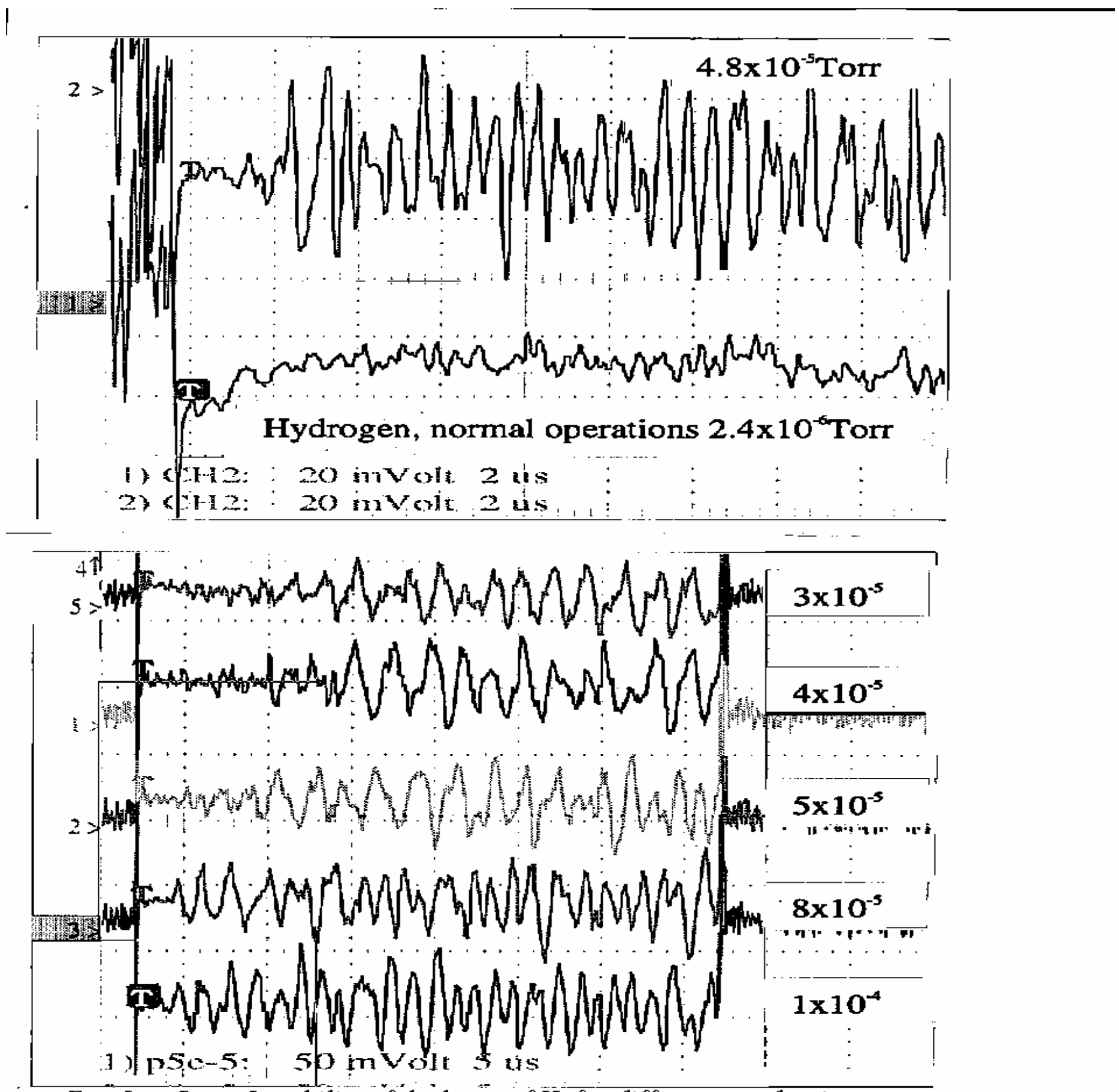


Fast Ion-beam instability of H- beam in FNAL Linac



Fast Ion- Beam Instability of the beam of H⁻ for different gas density

BPM

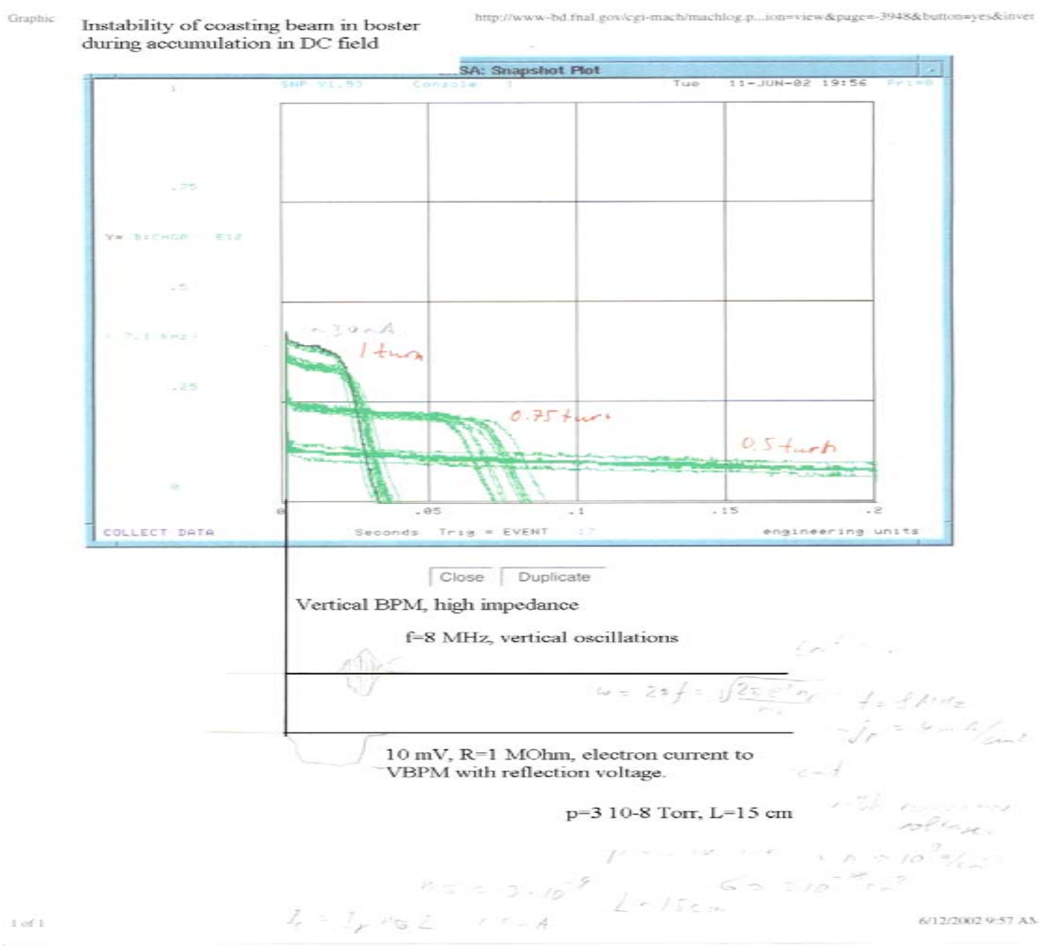
Signals

After

Preinjector

0.75 MeV

Transverse instability in FNAL Booster, DC B, Coasting beam



Secondary electron generation in the FERMOLAB booster, normal acceleration

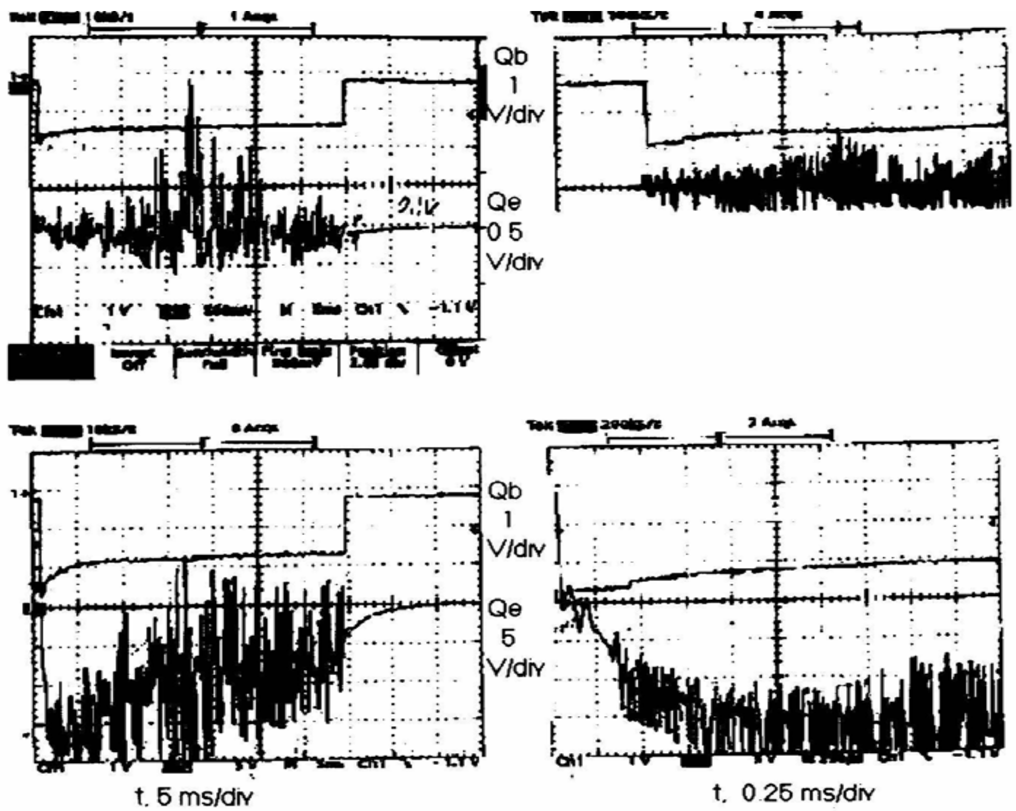
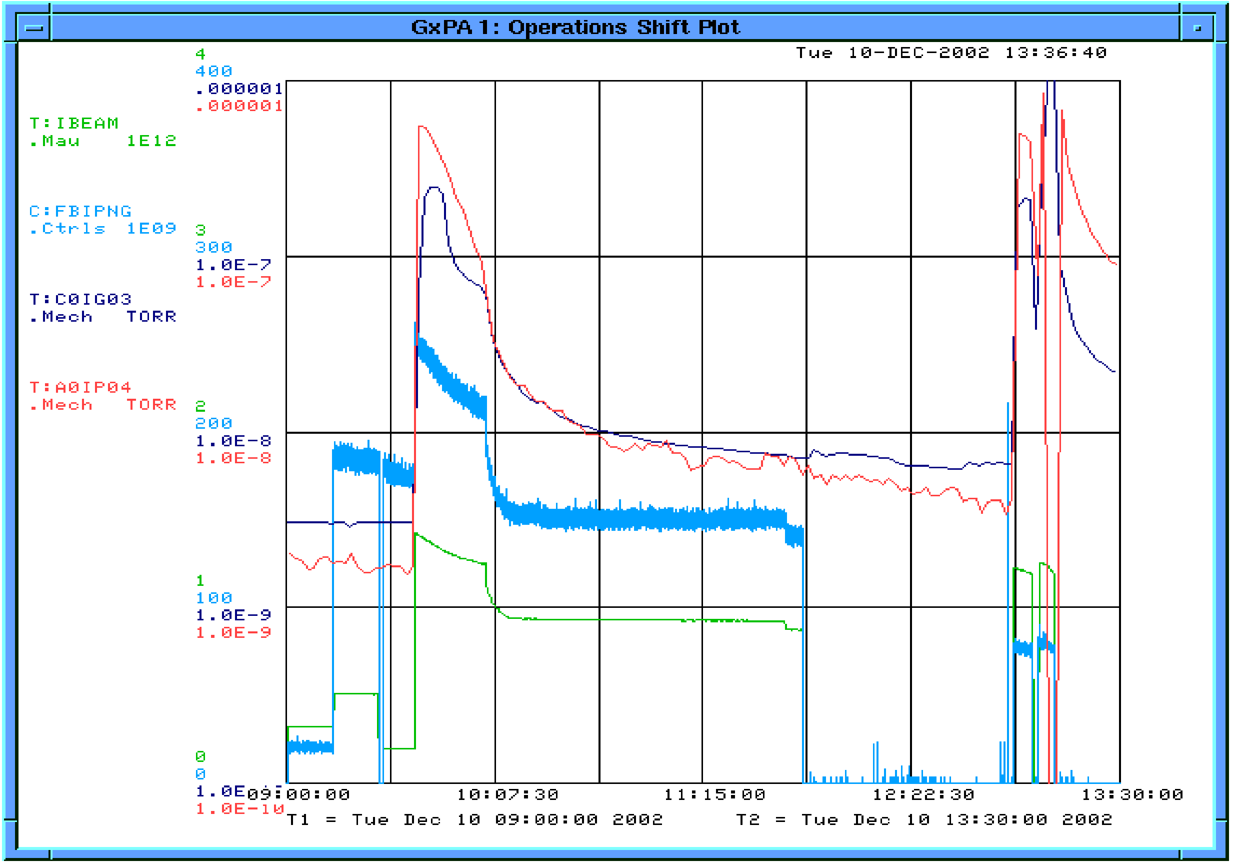


Fig. 1.Secondary electron formation in proton beam of booster
For different proton beam intensity Qb. Calibration 2E12p/V.
1 Channel: Proton beam intensity;
2 Channel: signal from reflecting plate of Ionization profile monitor (IPM). R= 1 Mohm.

Observation of anomaly in secondary electron generation in the FERMILAB Booster

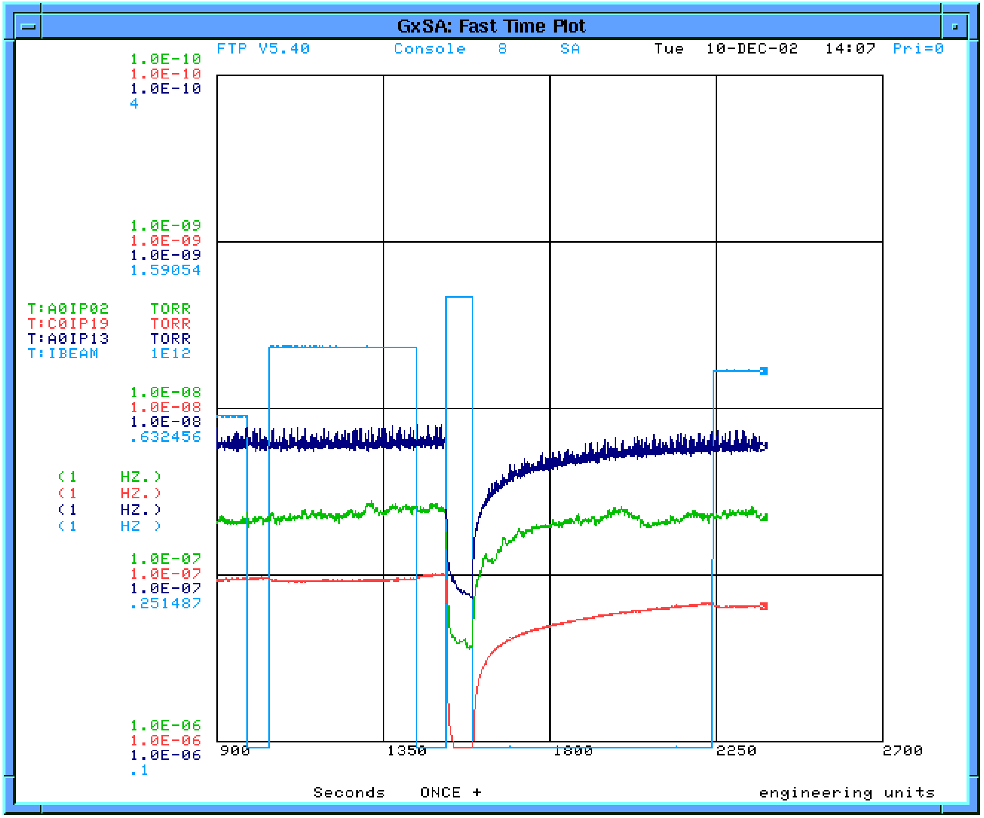
- Observation of secondary particles in the booster proton beam are presented in the Booster E-Log at 04/06/01 .
- Reflecting plate of the Vertical Ionization Profile Monitor (VIPM) was connected to the 1 MOhm input of oscilloscope (Channel 2).
- To channel 1 is connected a signal of proton beam Charge monitor Qb, with calibration of 2 E12 p/V.
- Oscilloscope tracks of the proton beam intensity Qb (uper track) and current of secondary particles (electrons) Qe (bottom track) are shown in Fig. 1 in time scale 5 ms/div (left) and 0.25 ms/ div (right).
- The voltage on MCP plate is Vmcp=-200 V.
- It was observed strong RF signal induced by proton beam with a gap (one long bunch). For intensity of proton beam Qb< 4E12 p electron current to the VIPM plate is low (Qe< 0.1 V~ 1E-7 A) as corresponded to electron production by residual gas ionization by proton beam.
- For higher proton beam intensity (Qb> 4E12p) the electron current to the VIPM plate increase significantly up to Qe=15 V~ 15 E-6 A as shown in the bottom oscillogramms. This current is much greater of electron current produced by simple residual gas ionization. This observation present an evidence of formation of high density of secondary particles in high intense proton beam in the booster, as in Los Alamos PSR and other high intense rings.
- Intense formation of secondary particles is important for the beam behavior and should be taken into account in the computer simulation.

Instability in the Tevatron



electron cloud instability in Tevatron, FNAL.
Change of vacuum and beam loss for diccerent beam intensity(green, blu).

Instability in Tevatron

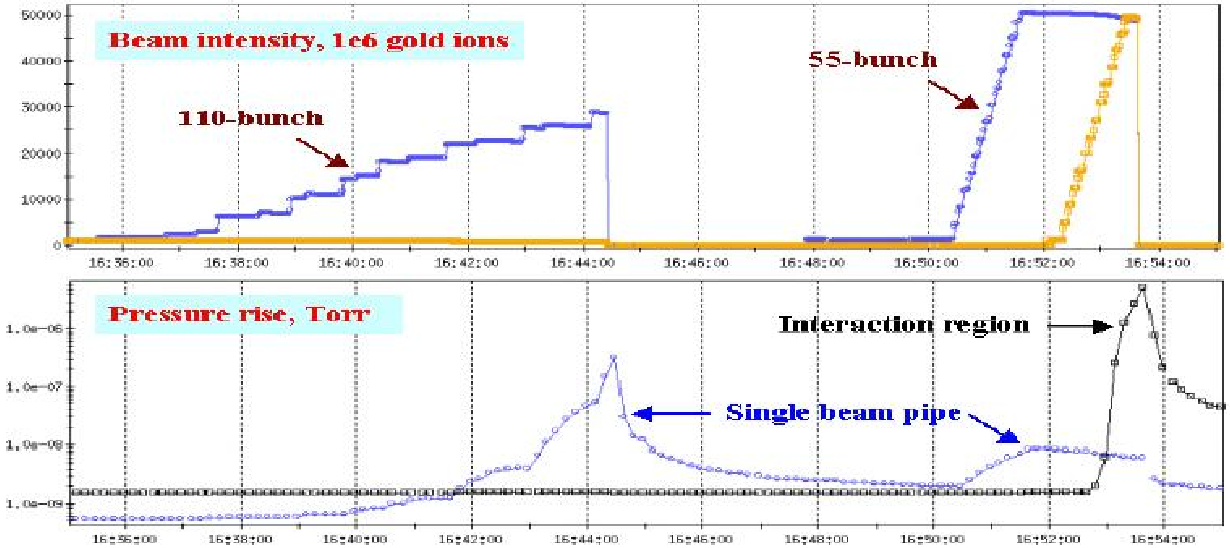


e-p instability in tevatrom. Change of vacuum for different beam intensity.

Instability in RHIC, from PAC03

BROOKHAVEN NATIONAL LABORATORY

Pressure Rise at Injection, I



- For gold beam 55-bunch injection with bunch intensity of 0.9e9 (design 1e9), the pressure rise at IR12 reached 1e-5 Torr, valve closed, and beam dumped.
- Pressure rise is very sensitive to bunch spacing, for 110-bunch fill, bunch spacing reduced from 216 ns to 108 ns, the pressure rise at single beam straight sections was much higher than 55-bunch mode.

Instrumentation for observation and damping of e-pinstability

- 1. Observation of plasma (electrons) generation and correlation with an instability development. Any insulated clearing electrodes could be used for detection of sufficient increase of the electron density. More sophisticated diagnostics (from ANL) is used for this application in the LANL PSR. These electrodes in different location could be used for observation of distribution of the electron generation.
- 2. For determination an importance compensating particles it is possible to use a controlled triggering a surface breakdown by high voltage pulse on the beam pipe wall or initiation **unipolar arc**. Any high voltage feedthrough could be used for triggering of controlled discharge. Could this break down initiate an instability?
- 3. For suppression of plasma production could be used an improving of surface properties around the proton beam. Cleaning of the surface from a dust and insulating films for decrease a probability of the arc discharge triggering. Deposition of the films with a low secondary emission as TiN. Transparent mesh near the wall could be used for decrease an efficient secondary electron emission and suppression of the multipactor discharge. Biased electrodes could be used for suppressing of the multipactor discharge, as in a high voltage RF cavity.
- 4. Diagnostics of the circulating beam oscillation by fast (magnetic) beam position monitors (**BPM).**
- 5. Beam loss monitor with fast time resolution. Fast scintillator, pin diodes.
- 6. Transverse beam instability is sensitive to the RF voltage. Increase of the RF voltage is increase a delay time for instability development and smaller part of the beam is involved in the unstable oscillation development.
- 7. Instability sensitive to sextuple and octupole component of magnetic field, chromaticity (Landau Damping), …

Electron generation and suppression

- Gas ionization by beam and by secondary electrons.
- Photoemission excited by SR.
- Secondary emission, RF multipactor.
- Unipolar arc discharge (explosion emission).
- Suppression:
- 1-clearind electrodes; Ultra high vacuum.
- Gaps between bunches.
- Low SEY coating: TiN,NEG.
- Magnetic field.
- Arc resistant material