Studies of Electron Cloud (ECLOUD) effects

Puneet Jain

High Energy Accelerator Research Organization (KEK)

What is ECLOUD?

Accumulation of electrons inside the beam pipe which, if sufficiently strong, can affect the machine performance by increasing the

Vacuum Pressure

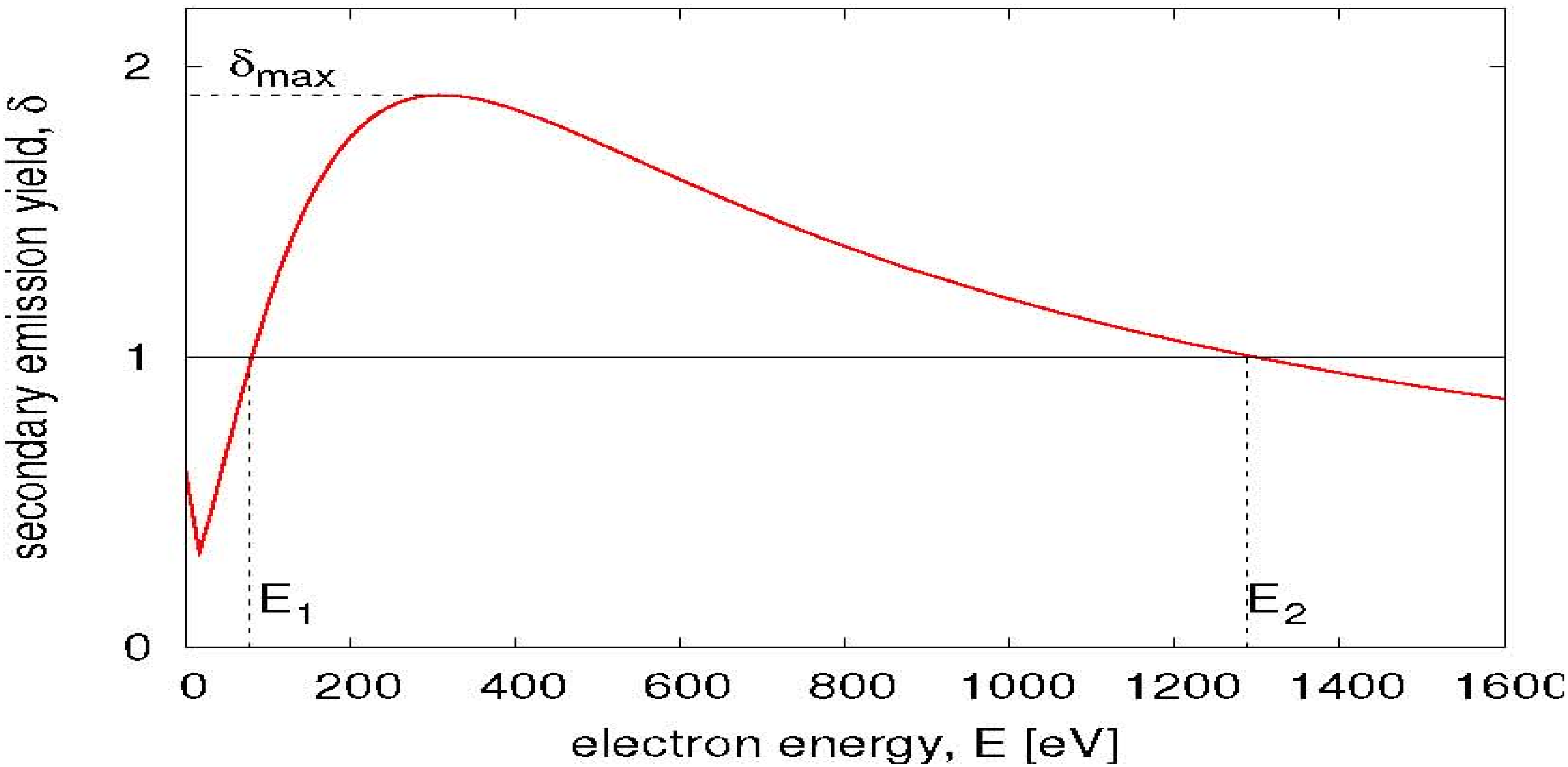
Producing Emittance Growth

Causing Beam Loss

Increasing Cryogenic Heat Load

Primary electrons – the seed of the ECLOUD are created by processes like FE, PE, Residual Gas Ionization…..

# of electrons ↑ due to SEY from the chamber wall - a process known as BEAM INDUCED MULTIPACTING (BIM).

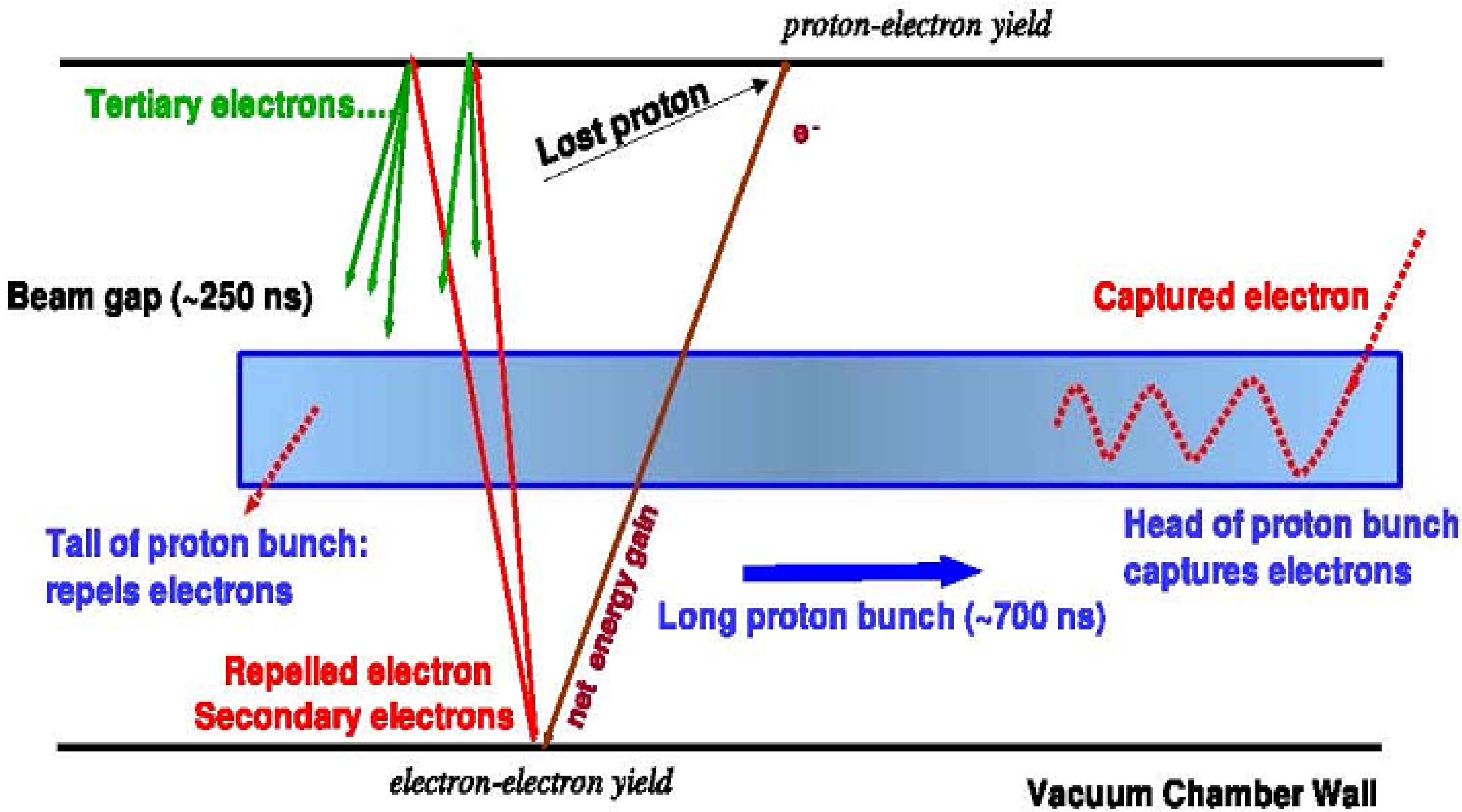


Typical behaviour of SEY (δ) as a fn of the impinging electron energy.

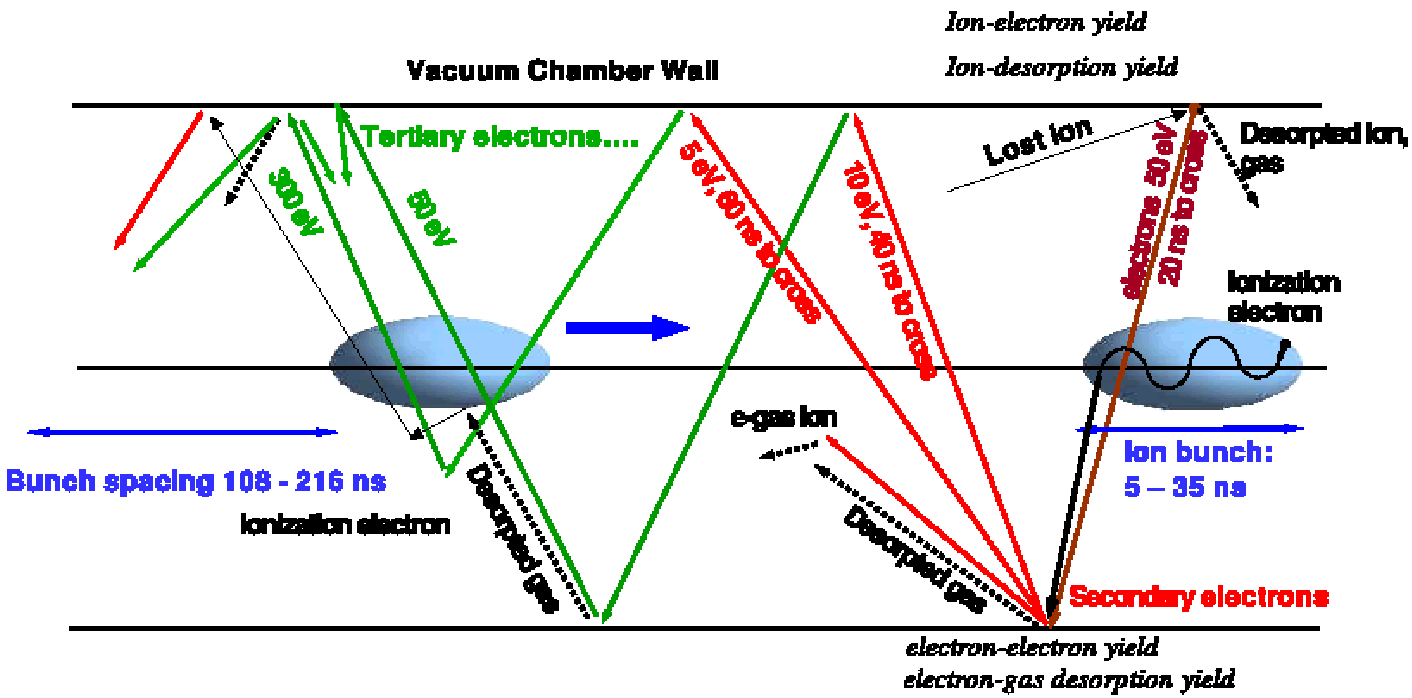
ECLOUD is mainly classified into two different regimes:

Single – bunch

Multi – bunch



SINGLE - BUNCH MULTIPACTING SCHEME



1. Primary Electrons

2. Electron acceleration

3. Electron multiplication

4. Electron survival
($t_{survival}$ ~ bunch spacing)

MULTI-BUNCH MULTIPACTING SCHEME

BIM – treated as resonance earlier, lead to : $N_b \leq b^2/r_e s_b$ (stringent condition)

ECLOUD can occur even for short bunch spacings (4-8 ns; positron beams in KEK-B and PEP-II), and long bunch spacings (25-200 ns; hadron beams in SPS or RHIC).

Due to purely EM nature of the interaction driving the ECLOUD mechanism, it has been found at electron beams also, albeit at a more modest level compared to positron beams in the same machine.

Even after a decade of intensive study, ECLOUD effects and instabilities continues to be an active research topic.

Development and implementation of cures remain very important for modern, high-performance accelerators.

I will now discuss the early history of ECLOUD observations.

- 1965 at INP Novosibirsk – first ECLOUD driven instability was made with a bunched beam at PSR.

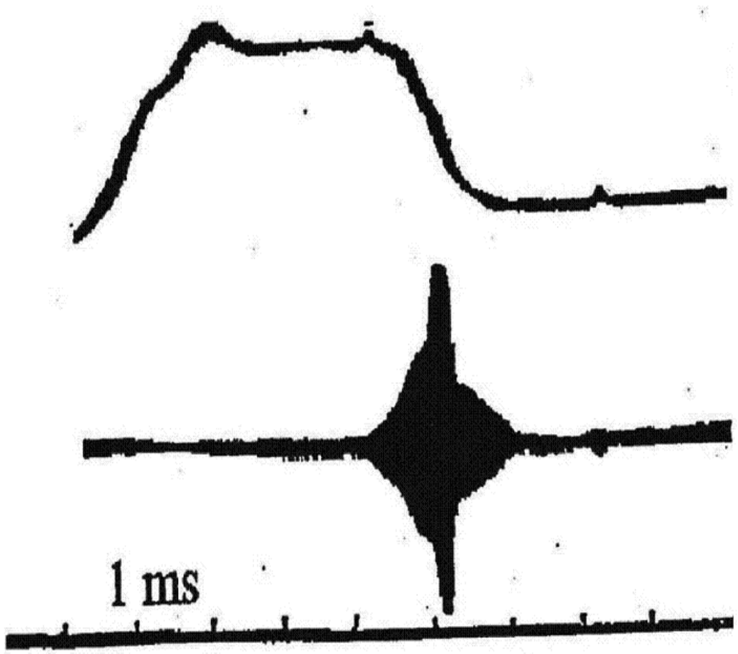


FIG. 1. Observation of an electron-driven instability at the INP PSR in 1965 [12]; beam intensity (top curve) and radial beam position (bottom curve) as a function of time (1 ms per division).

Ring Circumference : 2.5 m

Coherent betatron oscillations and beam losses occurred above a threshold proton intensity of 1-1.5×10^{10}

Problem was cured by a transverse feedback system

- 1967 – another PSR at INP suffered ECLOUD instability, with a coasting proton beam. The threshold here corresponded to 1.2×10^{11} protons, which were distributed over a 6 m circumference.

Cured by increasing the beam current and the gas density. New threshold $\sim 1.8\times10^{12}$

• 1965 – at Argonne ZGS, vertical instability was observed.

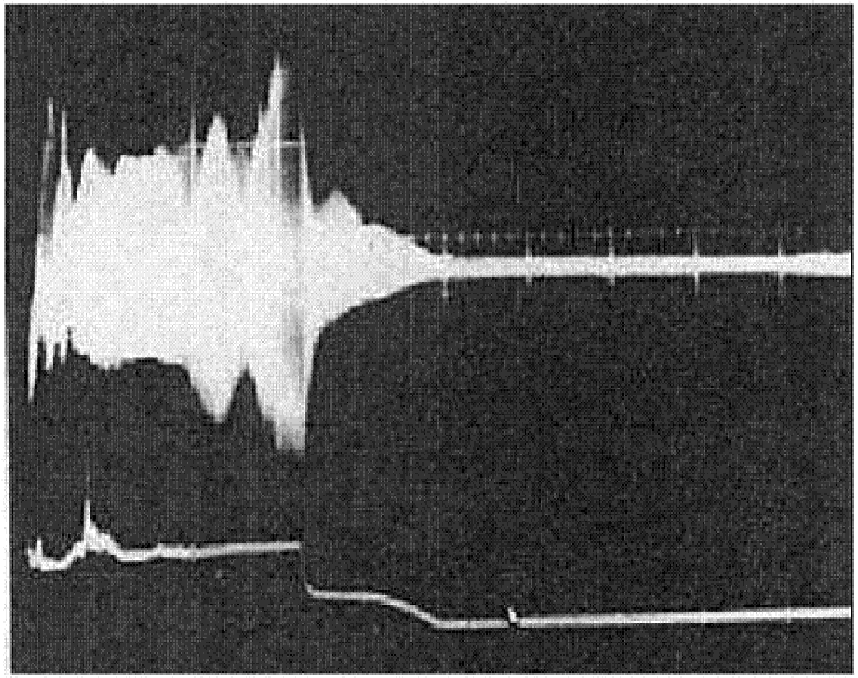


FIG. 2. Observation of coherent vertical instability at the Argonne ZGS in 1965 [18]; oscilloscope traces show the instability; the sweep rate is 0.2 s/cm; top trace: signal from a vertical pickup; bottom trace: beam current.

Instability growth time varied between 5 and 100 ms

Threshold varied from 2 to 8×10^{11} protons over 8 equally spaced bunches.

Most intense bunches were the most unstable and the threshold changed with the radial beam position.

Instability was suppressed with a transverse damper.

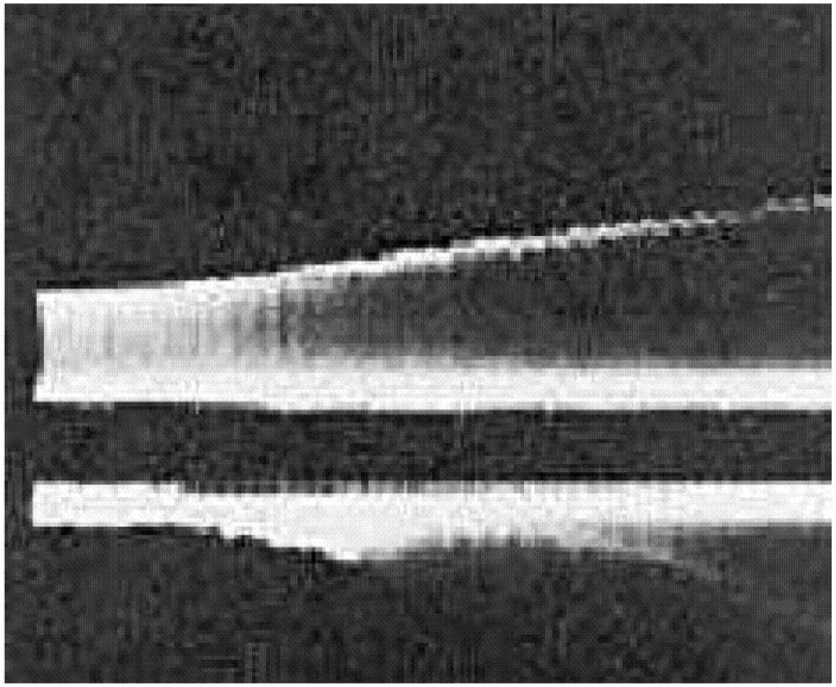
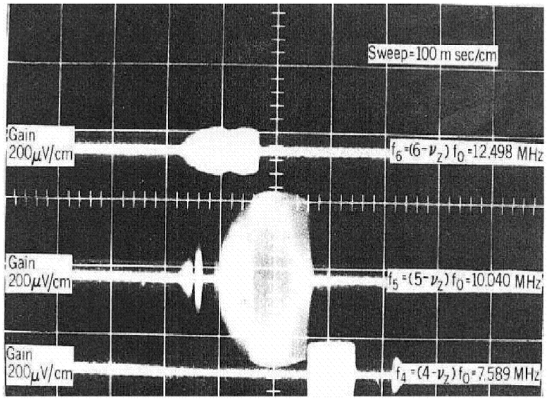


FIG. 3. Observation of coherent vertical instability at the BNL AGS in 1967 [20]; shown are the sum and difference signals from a vertical pickup; horizontal axis is time with 10 ms per division; the graph shows a 2 mm growth in peak-to-peak amplitude, at an intensity of 1.15×10^{12} protons.

Around same year, an e-related instability affected the operation of the BNL AGS.

- Coherent vertical betatron oscillations led to beam loss
- Instability caused by poor vacuum (10^{-5} torr over $^1/_{12}$ of the ring was sufficient to trigger the instability).
- Instability was suppressed by increasing the chromaticity with sextupoles.

• 1971 – BEVATRON also suffered from e-driven instability, with a coasting proton beam.



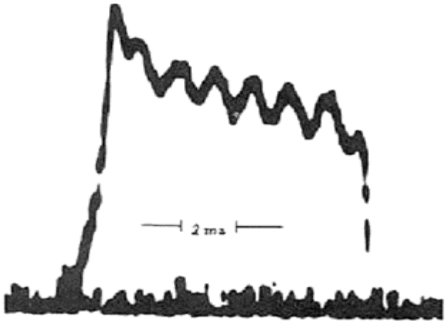
Oscilloscope traces show the amplitudes of modes **6**, **5**, and **4** as a function of time.

All modes with 'n' b/w 3 and 10 were observed to become unstable, successively in time.

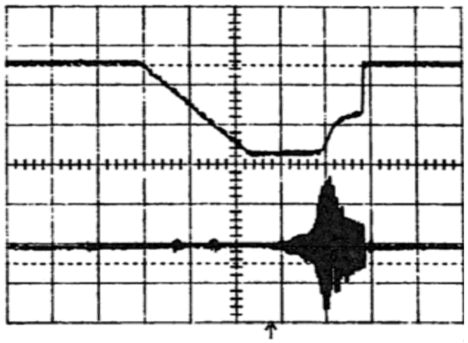
Unstable mode # changed towards smaller values as the instability progressed – attributed to the decrease in the oscillation freq of the electrons for increasing beam size. For 10^{12} protons per pulse, the beam size doubled in 200 ms at 2×10^{-6} torr vacuum.

CLEARING FIELDS were applied, that decreased the oscillation amplitude by a factor of 2.

The instability was **NOT** very sensitive to the settings of the octupoles.

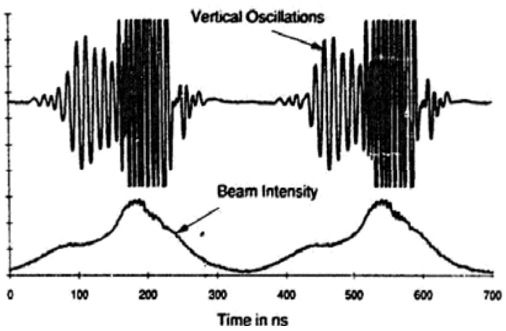


Observation of coupled e-p instability at the CERN ISR (1972); shown is the beam-induced signal from a horizontal pickup; the instability had a fast rise time and lasted for 5-10 ms.



e-cloud instability was also observed at the Los Alamos PSR (1988); vertical betatron oscillation starts, grows, and results in beam loss;

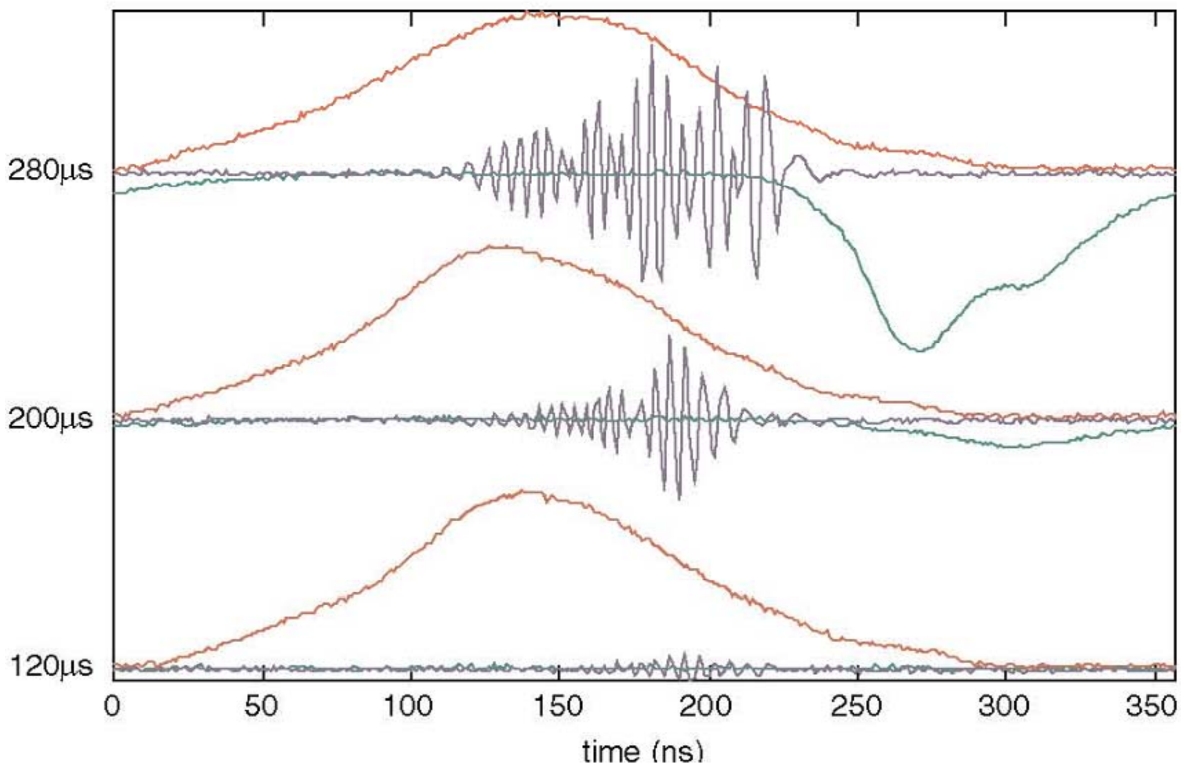
Lower figure shows the same type of signal on a different time scale, namely, recorded over two successive turns.



Focus was on quickly stabilizing the beams and not on extensive academic study.

Systematic program of experimental study began when similar observations were made at PSR machine at LOS ALAMOS around 1988.

PSR Instability results illustrate the progression of the instability from the end of the bunch towards the front, and that for the PSR **electron production** and **instability** should be considered as a **combined process**.



Evolution of the vertical PSR Instability

Gaussian-like trace is the beam current,

Oscillating trace is the vertical beam position (difference signal),

Negative curve is the electron current measured at the wall.

In 1989, wideband vertical multibunch collective instability was observed for the first time in e^+ ring of the KEK Photon Factory (PF).

Prof Izawa [PRL **74**, 5044 (1995)]:

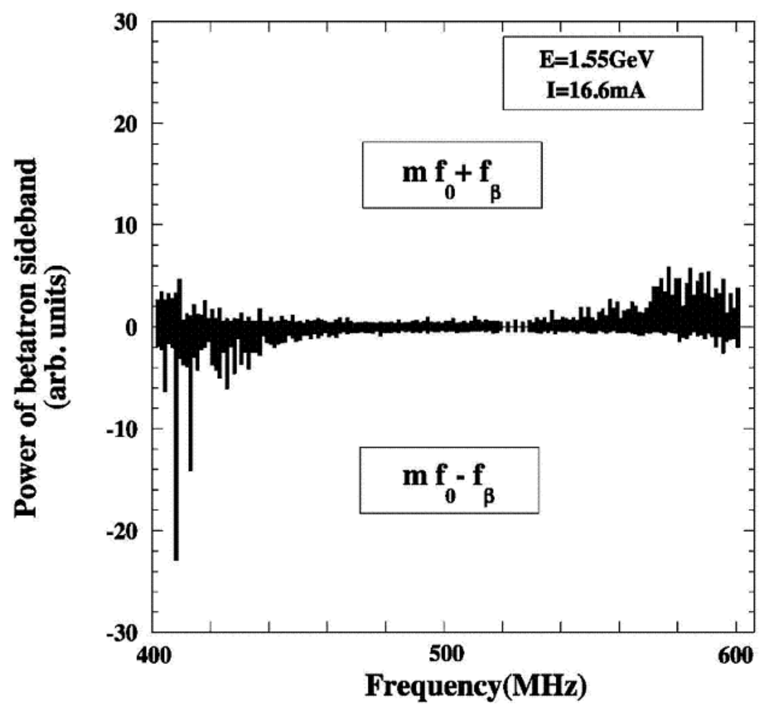
- Instabilities NOT attributed to transverse wake fields induced by beam-wall interactions

- Possible sources of these instabilities were e^- in case of a positron beam and trapped ions in the case of an electron beam

A team of KEK scientists (Y. H. Chin, H. Fukuma, S. Hiramatsu, M. Izawa, T. Kasuga, E. Kikutani, Y. Kobayashi, **S. Kurokawa**, K. Ohmi, Y. Sato, Y. Suetsugu, M. Tobiyama, K. Yokoya, X. L. Zhang) performed the experiments at BEPC, China in collaboration with Prof Z.Y.Guo and his co-workers and found a similar **vertical coupled-bunch instability** for positron beam.

Vertical betatron sidebands at a beam energy of 1.55 GeV.

Positive and negative values correspond to mf_0+mf_β and $mf_0 - mf_\beta$ respectively.



Anomalous growth of the horizontal coupled bunch modes of the bunched beam was observed at CESR (1997). Attributed to the photoelectrons which were trapped in the beam chamber by the BM field and a quadrupole.

The investigation at the KEK PF was the first one that revealed an ECLOUD effect for lepton beams.
It steered in the “modern-era” of the effect, sparking substantial and widespread interest.

Transverse single-bunch instabilities were first observed in positron rings at the KEK B and SLAC PEP-II B factories ~ 1999-2000 timeframe.

Observations and Experiments:

- Measurement of Electron Yield – RFA
- Pressure Rise
- SEY measurement
- Instabilities
- Betatron tune shift
- ECLOUD in magnets

Modeling and Simulation:

- electron cloud build up- RFA
- coupled bunch instability
- single bunch instability
- code-to-code benchmarking

Codes developed: CLOUDLAND, CSEC, ECLOUD, PEI, POSINST (EC buildup) ECI, HEADTAIL, PEHT, PEHTS, QUICKPIC (Instability Simulation)

Cures:

- Coating and Scrubbing
- Grooved Surface
- solenoid
- Clearing Electrode
- Anti-grazing ridge
- Active feedback system

Acknowledgement:

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THANK YOU.