Study of Photoelectron Instability at the BEPC

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1. Introduction
2. Instrumentations
3. PE Measurements
4. Simulations
5. Discussions

1. Introduction

- Many experiments on photoelectron instability (PEI) carried out at the Beijing Electron Positron Collider (BEPC) in IHEP, China, in collaboration with KEK since 1996.

- A specially-constructed detector installed at the BEPC, based on the detectors at Advanced Photon Source (APS), ANL.

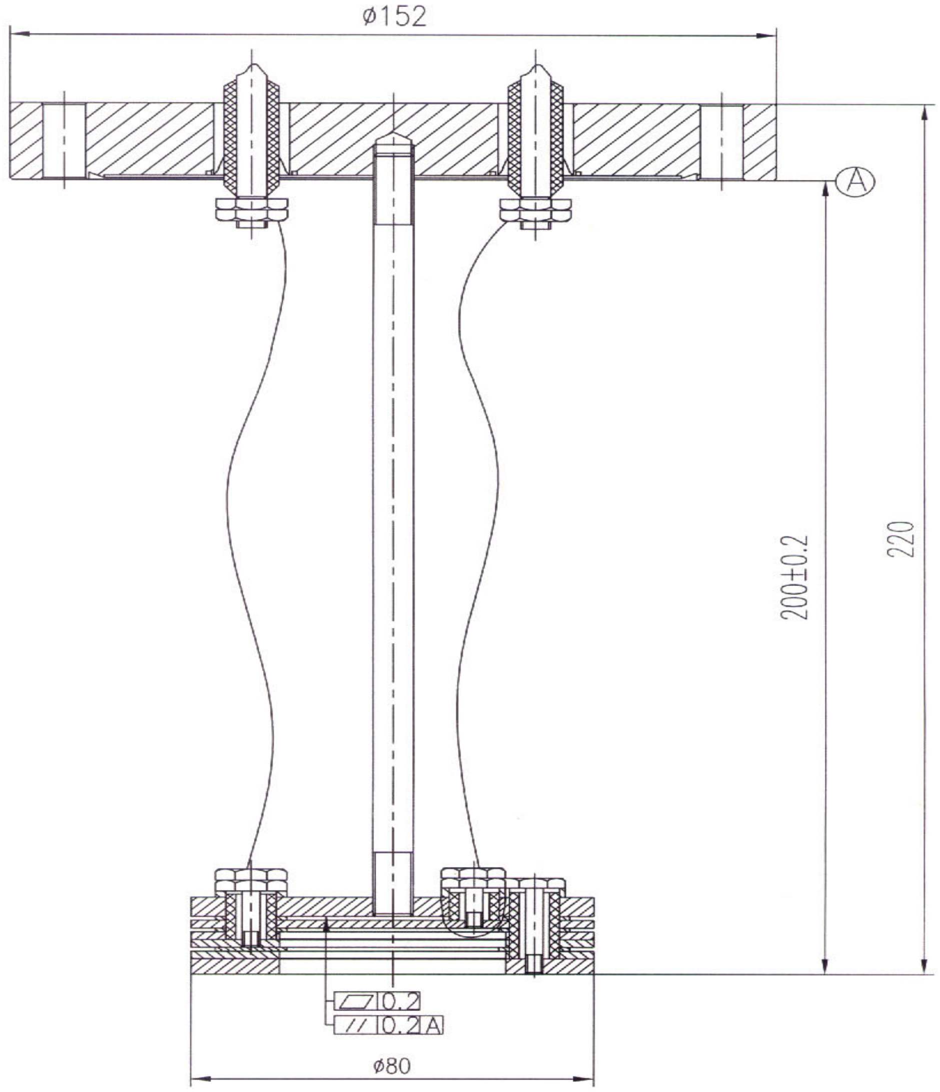
- Properties of the photoelectron (PE) cloud for both stable and unstable beams can be directly measured with the detector, and the secondary electron as well as the energy spectrum is hoped to obtain.

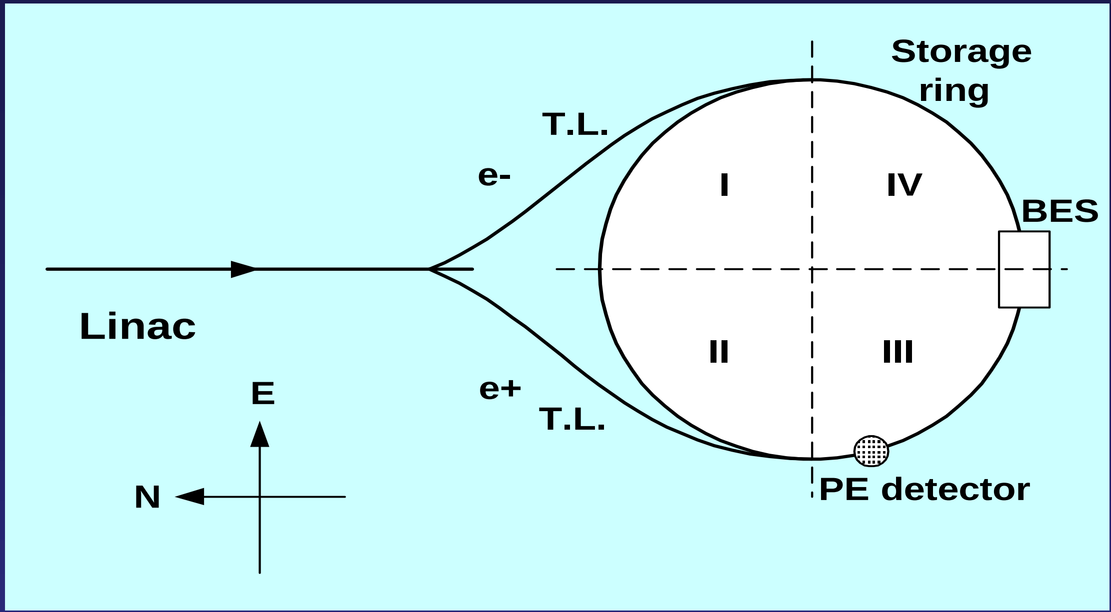
- In this paper, the experimental results at the BEPC are presented after the description of the instrumentation. Some simulation results and discussions are followed.

2. Instrumentations

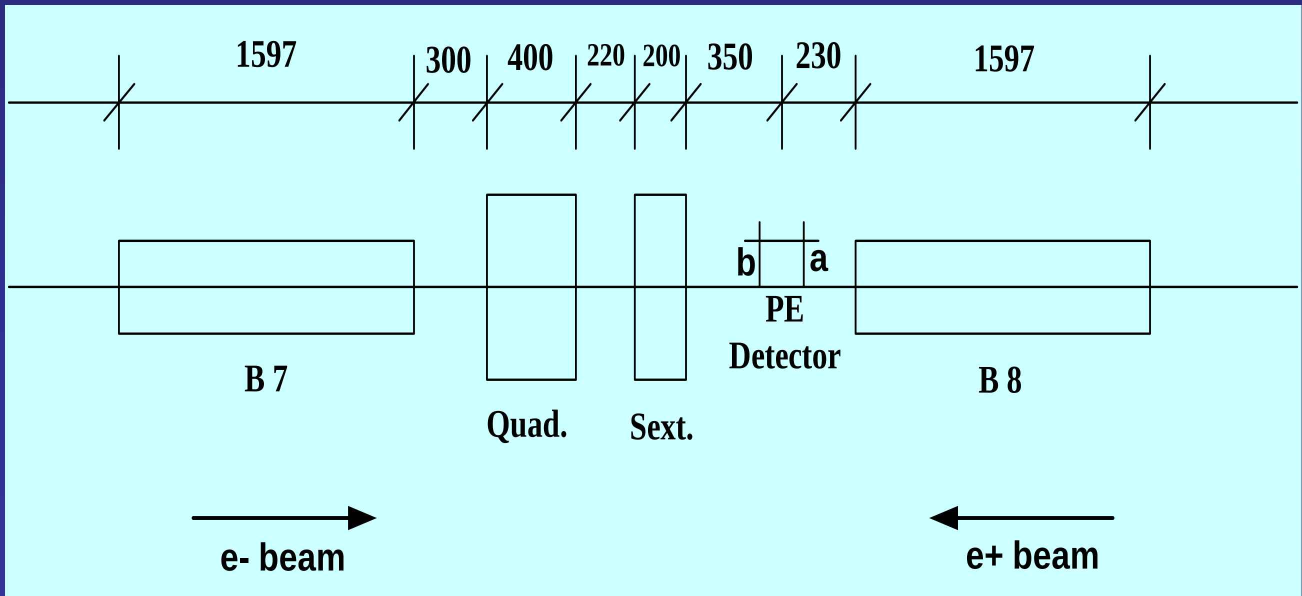
2.1 The PE Detector

- Three layers , ϕ 80 mm
- Two mesh grids in front of the detector.
- Grounded outermost grid, a bias voltage applied to the shielded grid.
- Graphite-coated collector to lower the secondary electron yield and is biased with a DC voltage of +48 V.
- Mounted on an idle profile slot, the detector is ϕ100 mm, located on the top of the vacuum chamber.

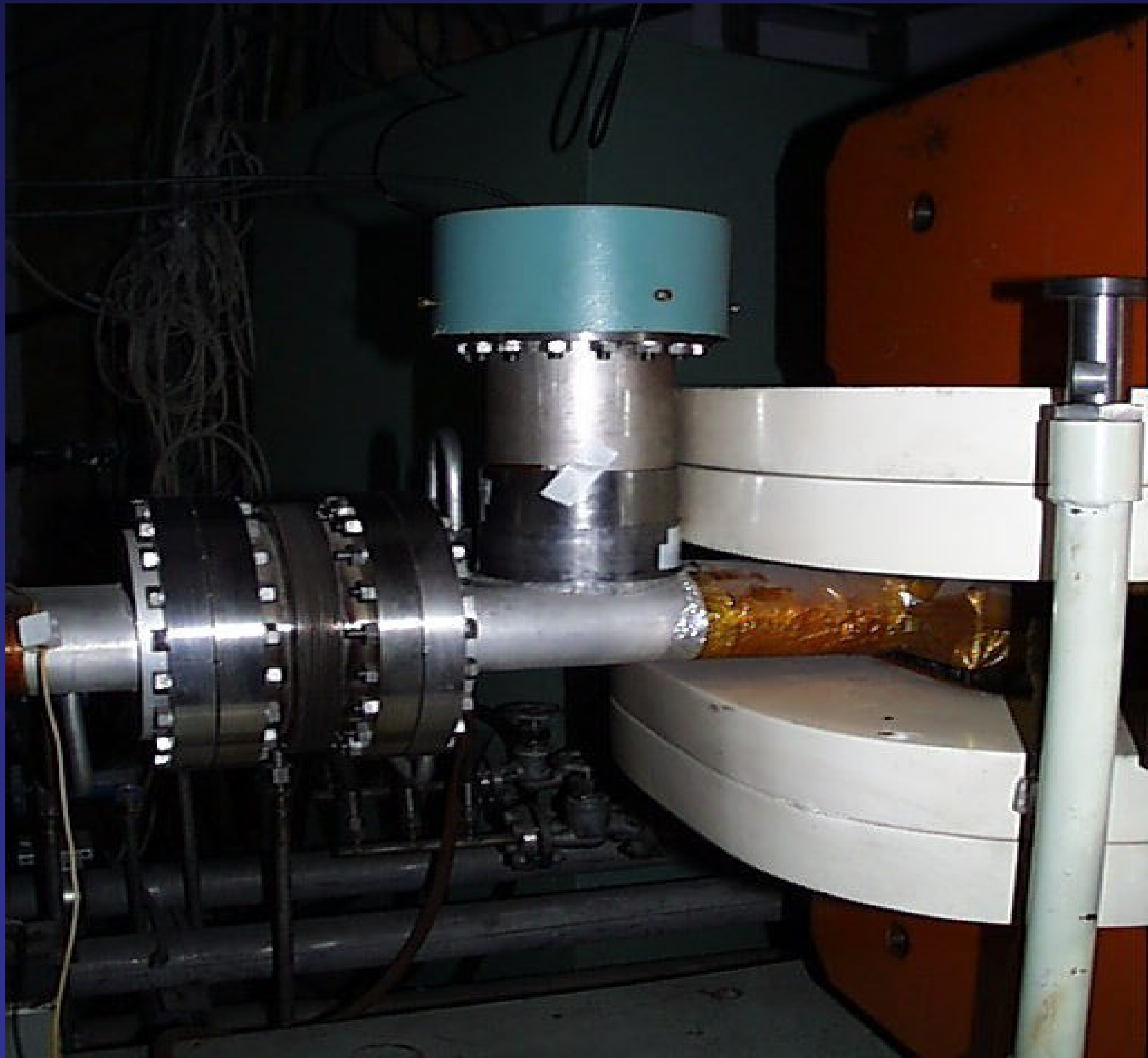




Storage
ring
T.L.
e-
I
IV
BES
Linac
II
III
E
e+
T.L.
N
PE detector

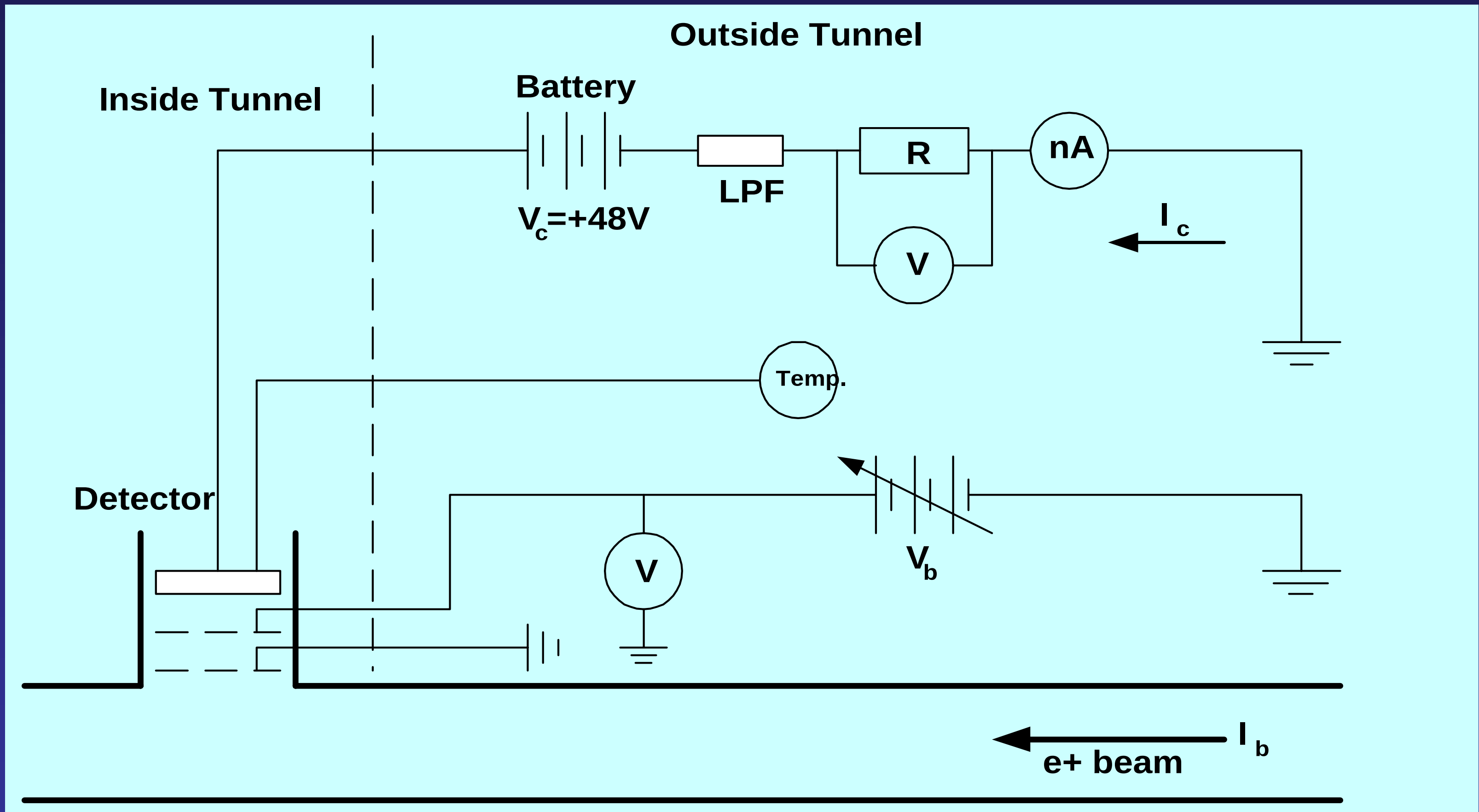


1597
300
400
220
200
350
230
1597
b
a
PE
Detector
B 7
B 8
Quad.
Sext.
e- beam
e+ beam



The shielded PE detector after mounted on the BEPC storage ring

2.2 Apparatus Setup



2.3 Machine and Beam Parameters

Main parameters of the BEPC storage ring

Beam Energy	1.3 GeV	Critical Energy	0.471 keV
Circumference	240.4 m	Rev. Frequency	1.247 MHz
Dipole Field	0.419 T	Dipole Length	1.597 m
Bending Angle/dipole	0.1547 rad	Bending Radius	10.336 m
RF Frequency	199.536 MH	Harmonic Number	160
RF Voltage	0.2 ~ 1 MV	Bucket Length	5 ns
SR Energy Loss/turn	24.3 keV	Beam Energy Spread	3.46×10^{-4}

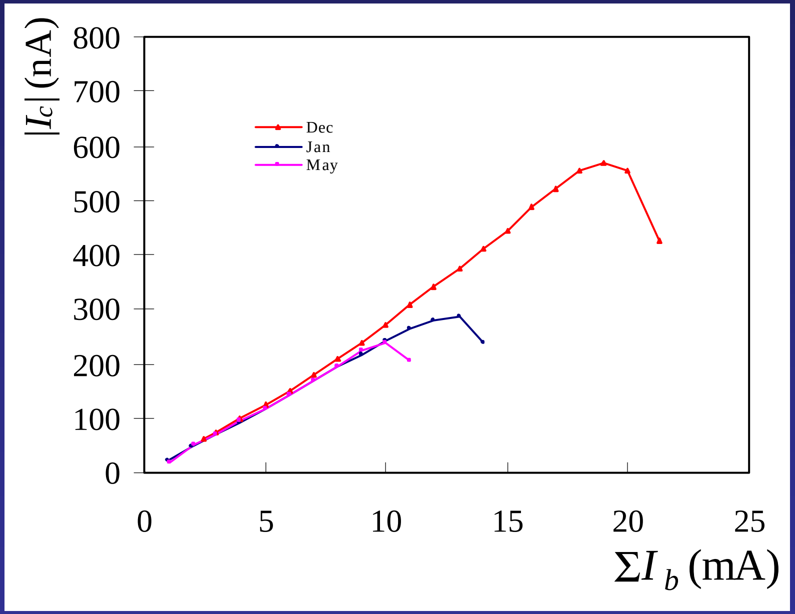
Main parameters of different optics used in PE measurements

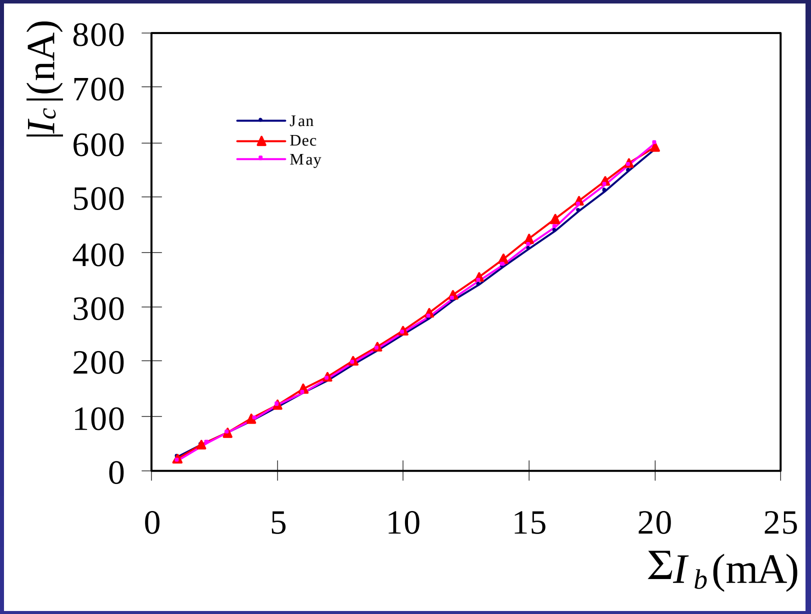
Beam Parameter	165 #	14#	89#
Emittance	0.3 mm·mrad	0.13 mm·mrad	0.028 mm·mrad
Mom. Compact	0.044	0.036	0.016
Trans. Tunes	5.82/6.75	5.82/6.74	8.72/4.75
Natural Chrom.	-10.68/-17.04	-8.18/-10.08	-13.10/-7.53
Chrom. with sext.	6.00/6.00	4.00/4.00	1.5/1.5
β_x at PE detector	12.05 m	6.62 m	6.27 m
β_y at PE detector	5.15 m	5.45 m	7.19 m
η_x at PE detector	2.22 m	1.63 m	0.67 m
H/V coupling	~ 5%	~ 5%	~5%

3. PE Measurements

3.1 Instrumentation check with beam

- An LPF to filter the beam-induced RF noise.





No LPF

With a 150-MHz LPF

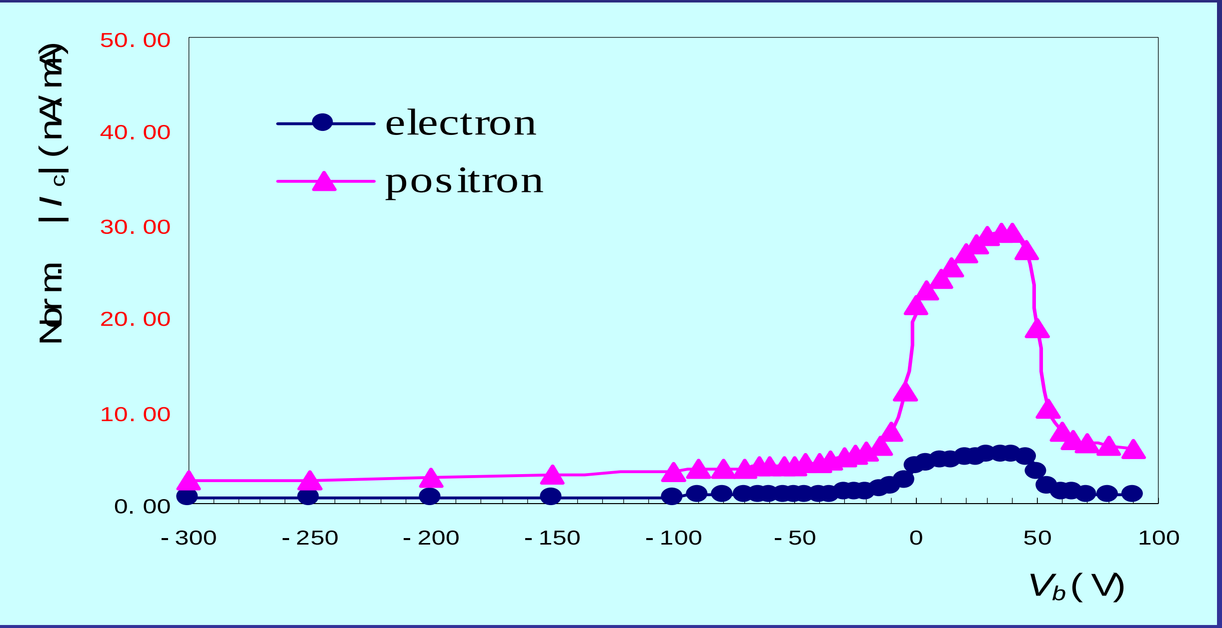
- A 150-MHz LPF applied to eliminate any sources of noise.

- A 0.1 MΩ resistor is connected, checking the direction of the current from the collector with a voltmeter connected across the resistor.

- The nanoammeter, connected between the resistor and ground, cross-checked with the readings of the voltmeter.

- The temperature monitor displays 24±1°C with no change, showing no HOMs effect due to the annular gap between the detector and its support barrel.

- V_b is fixed at +40V for maximum signal via bias voltage scan.



- Electron beam creates a PE signal that is about 6 times lower than positron beam.

- Possible Reasons:

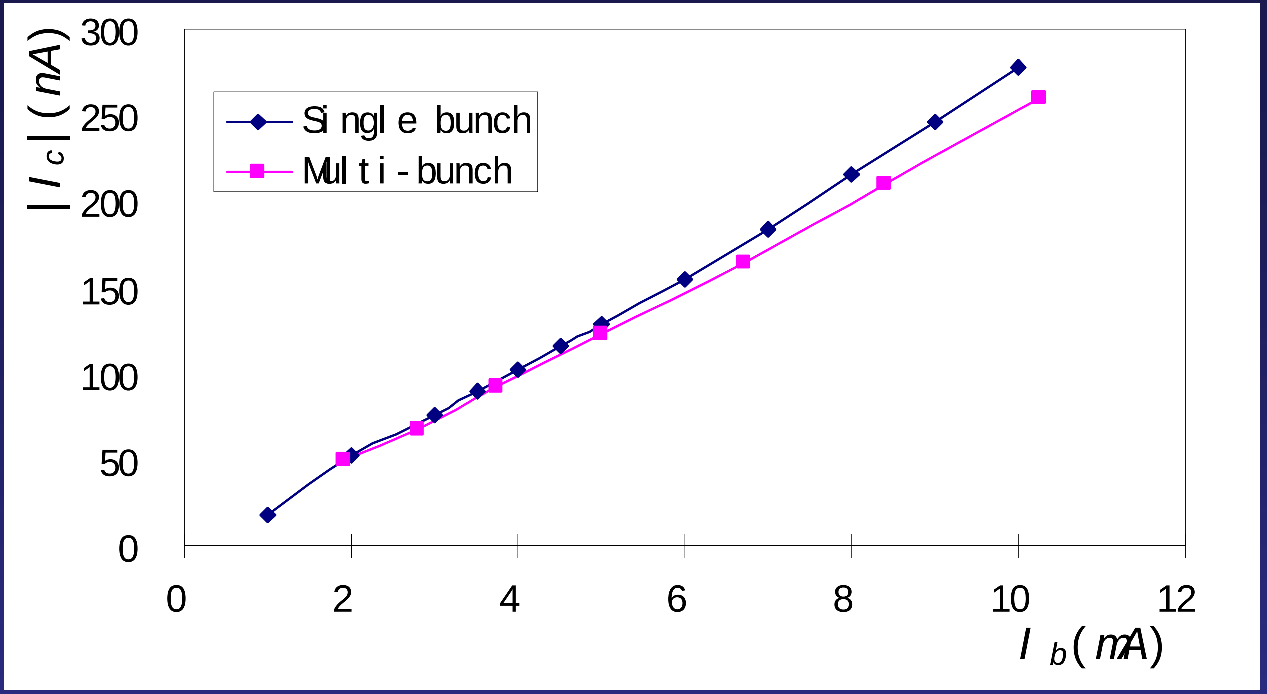
  1) The detector is located 6 times closer to the downstream dipole (B8) for positron beam than the distance from detector to the downstream dipole (B7) for electron beam.

  2) The interaction of PE and positron beam may cause more electrons to be deflected into the detector.

- Then, positron beam is selected in the whole experiment.

3.2 Dependence on beam current

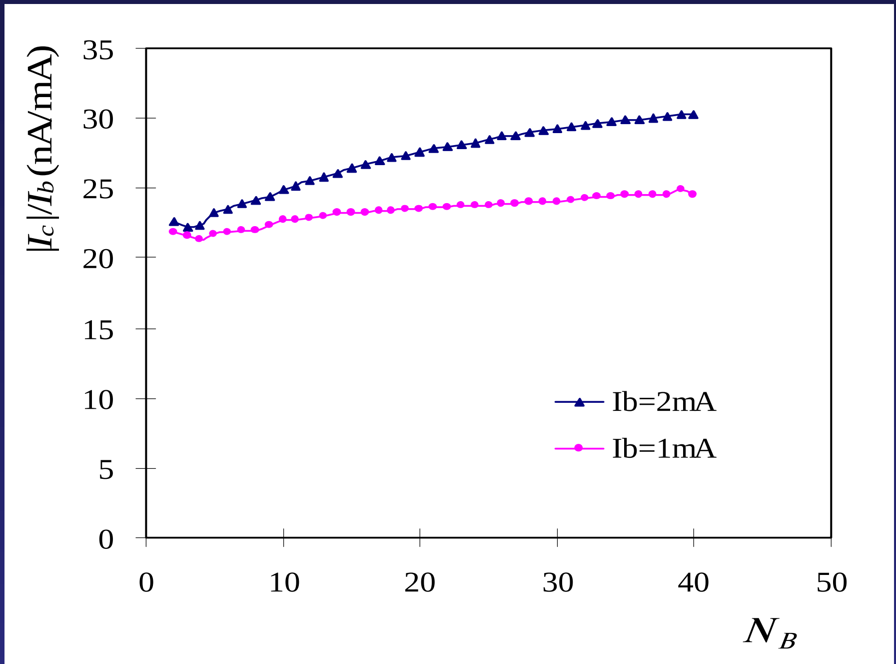
- Compare the single bunch and multi-bunch cases



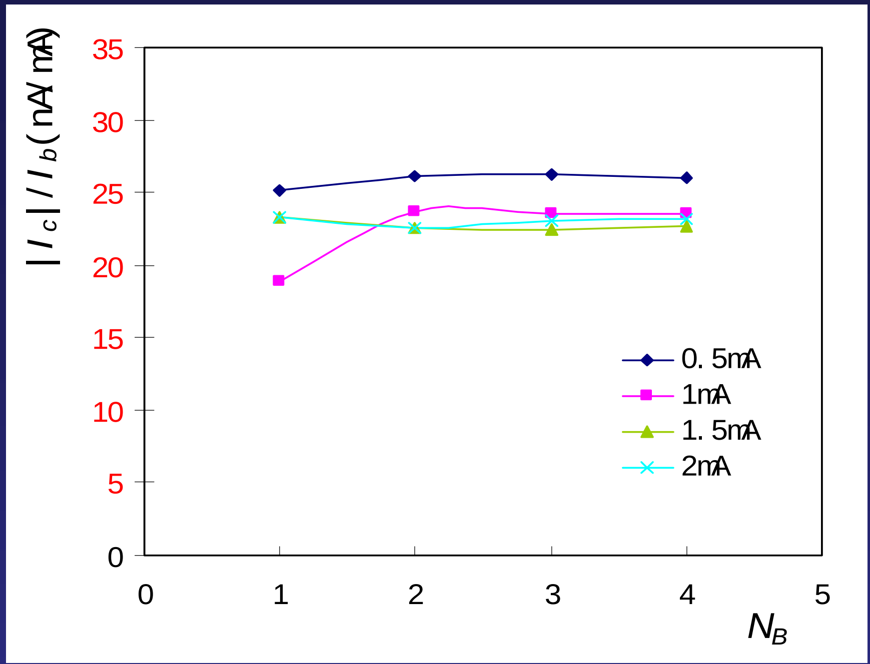
No significant difference between the single bunch and multi-bunch cases

- **Effect of bunch train length**

Compare the cases of bunch spacing = 2 and 5 buckets



$|I_c|/I_b$ (nA/mA)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
N_B
Ib=2mA
Ib=1mA

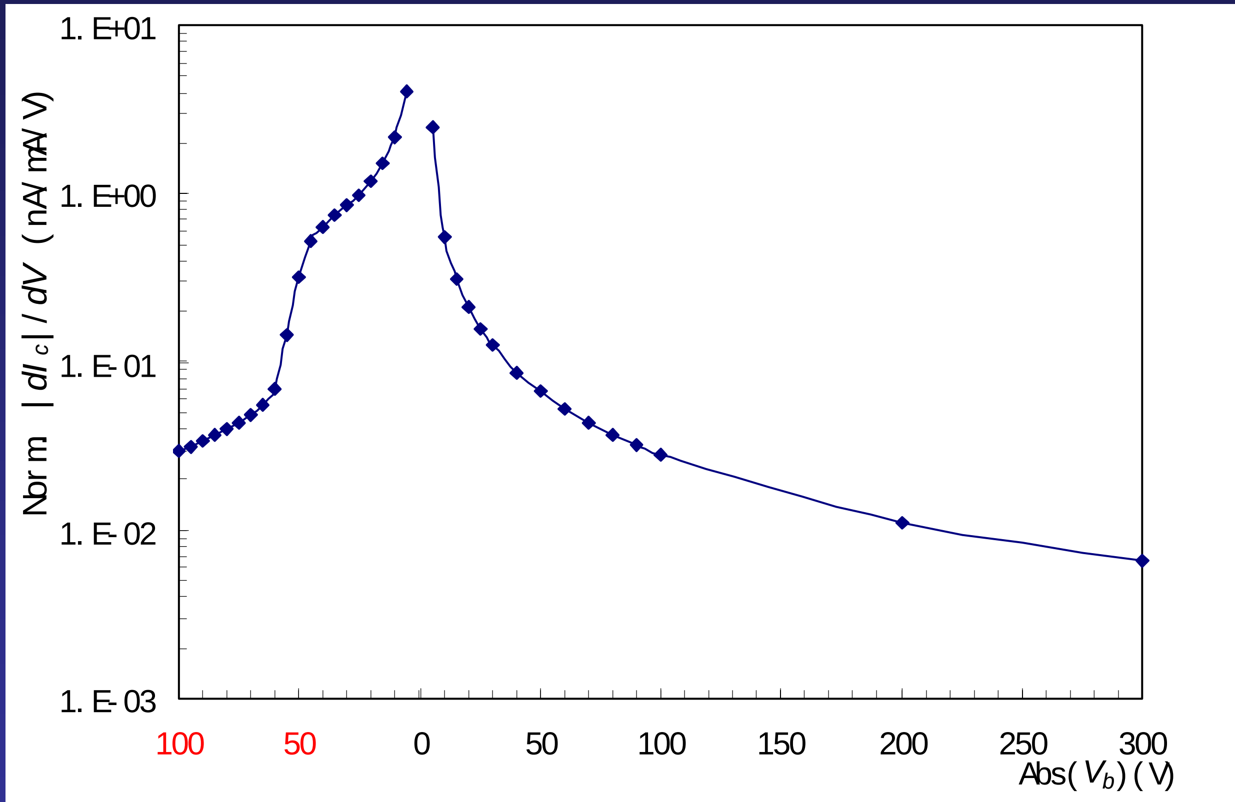


$|I_c|/I_b$ (nA/mA)
35
30
25
20
15
10
5
0
0
1
2
3
4
5
N_B
0.5mA
1mA
1.5mA
2mA

$S_b = 2$

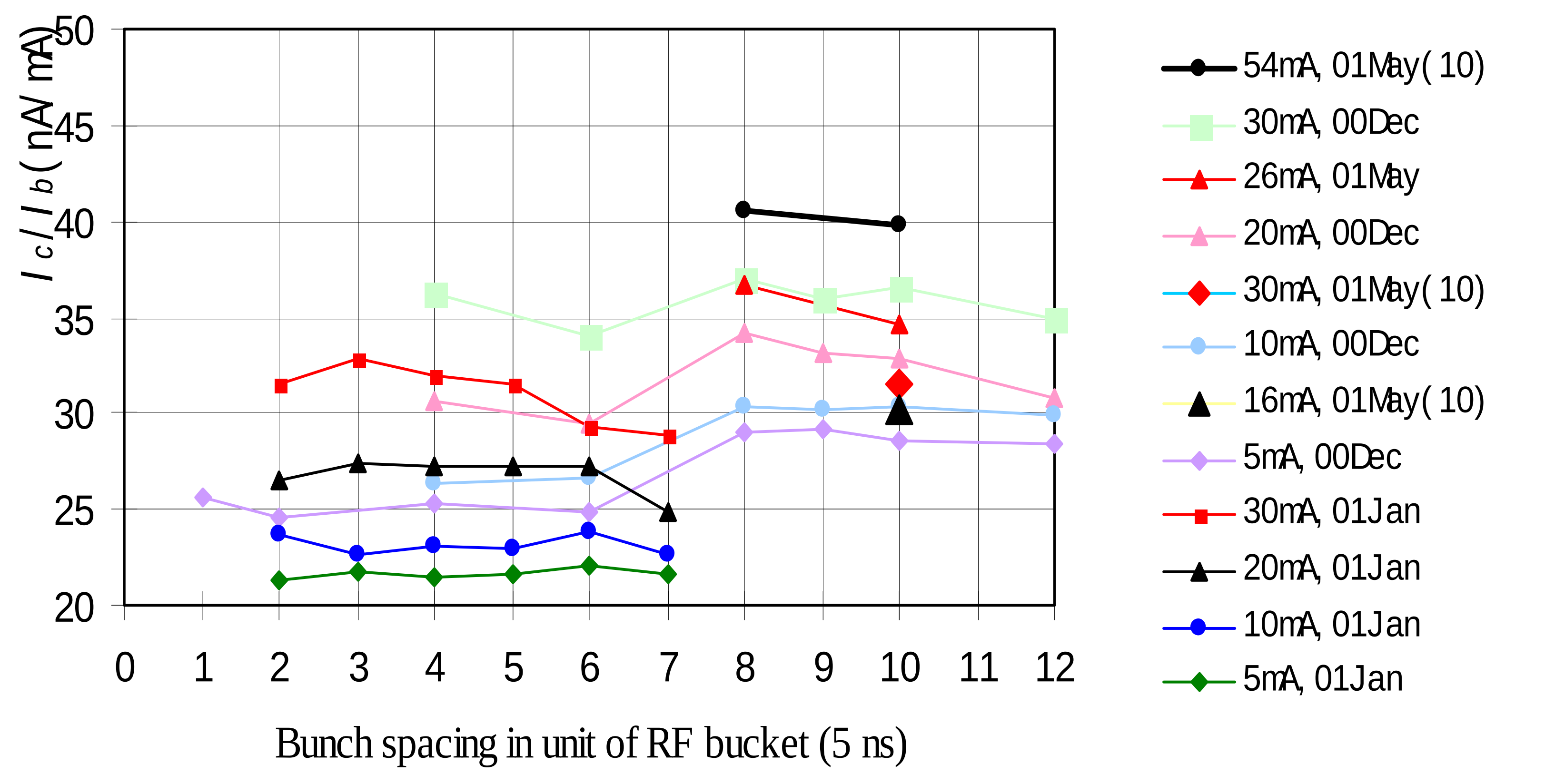
$S_b = 5$

- **The derivative of the normalized I_c-V_b curve gives the photoelectron energy distribution**



3.3 Secondary electron (SE) measurement

- **A dramatic amplification of the signal is observed in the APS when the bunch spacing is 7 buckets (20 ns) due to the SE.**
- **The energy gain of the electrons kicked by the beam is determined by $\Delta p = 2m_e N_b r_e c/a$, a - the radial distance from the beam, r_e - the classical electron radius.**
- **The beam-induced multipacting may be expected to appear on 5-bucket spacing and 6 mA/bunch in the case of BEPC.**
- **But in the measurement, such amplification is not obtained when the bunch spacing and current are scanned from 1 mA/bunch to 6 mA per bunch with the bunch spacing from 1 to 12 buckets in a bunch train of 5 and 10 bunches.**

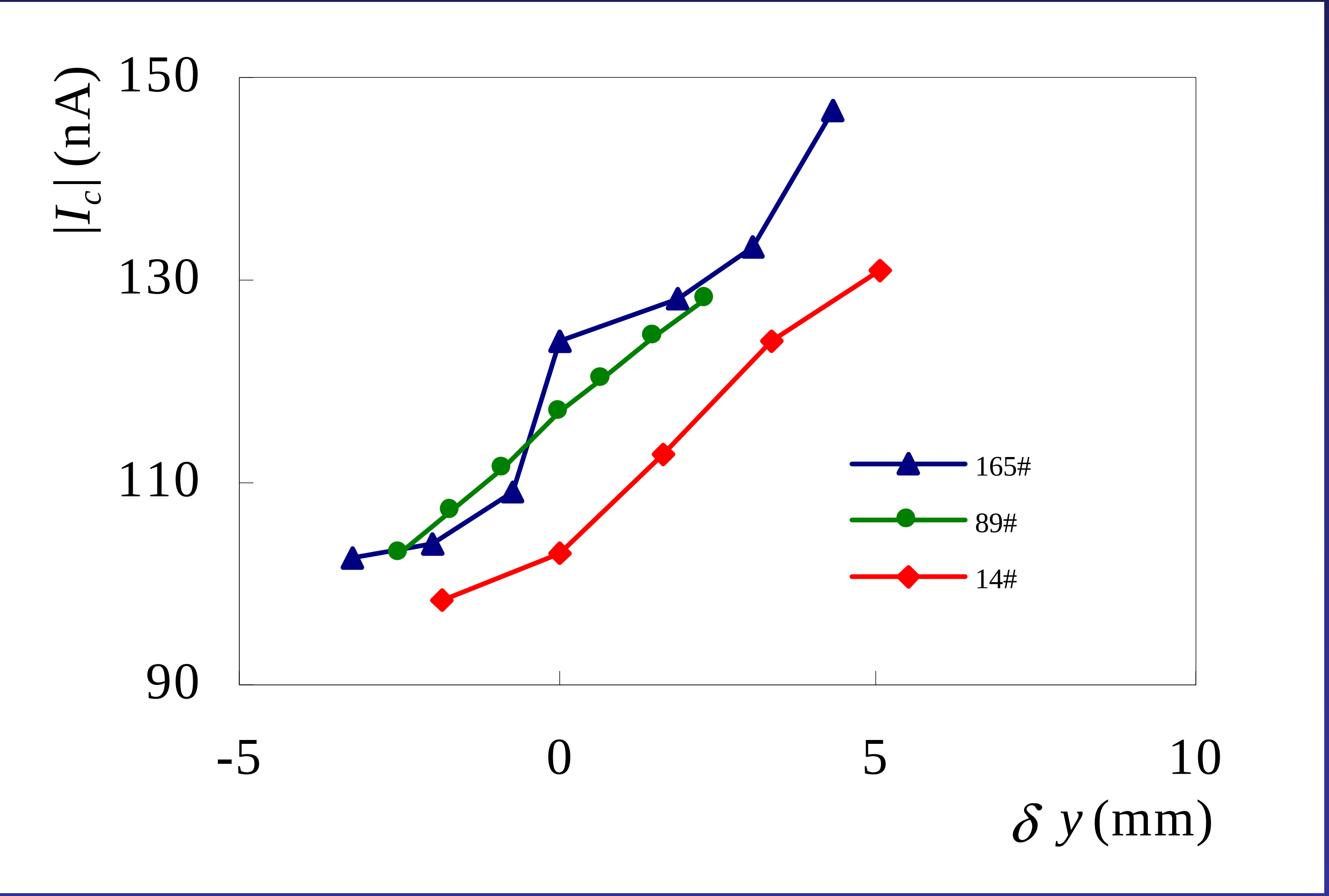


- **The only result is the normalized electron current increases when increasing the bunch current.**

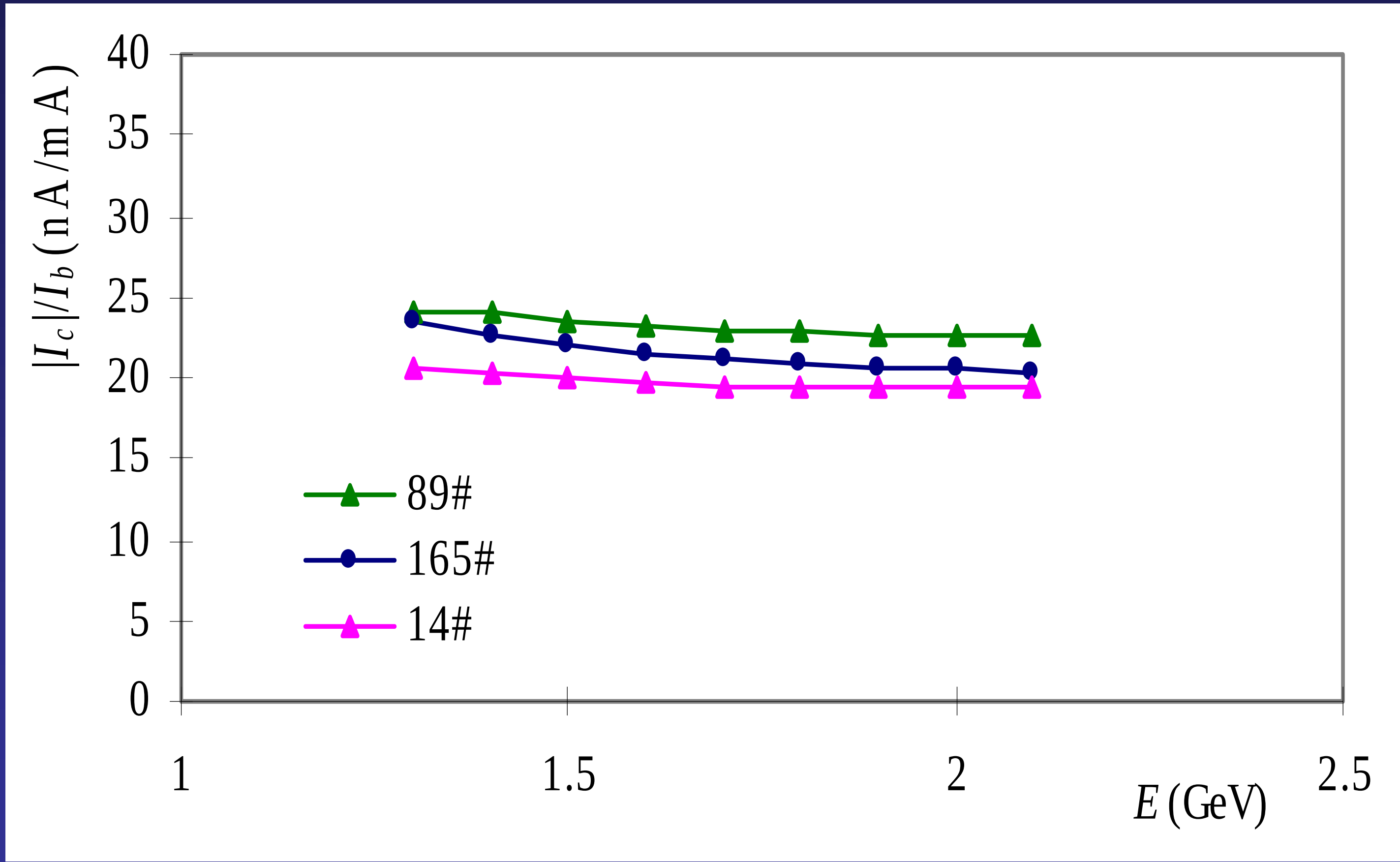
- **Possible reason: the short distance between the bending magnet and the detector, which may cause the photoelectrons to dominate and possibly suppress the secondary electrons.**

3.4 Dependence on beam parameters

1) C.O.D $\Delta I_c / \delta y \sim 1$ nA/mm @ $I_b = 1$mA

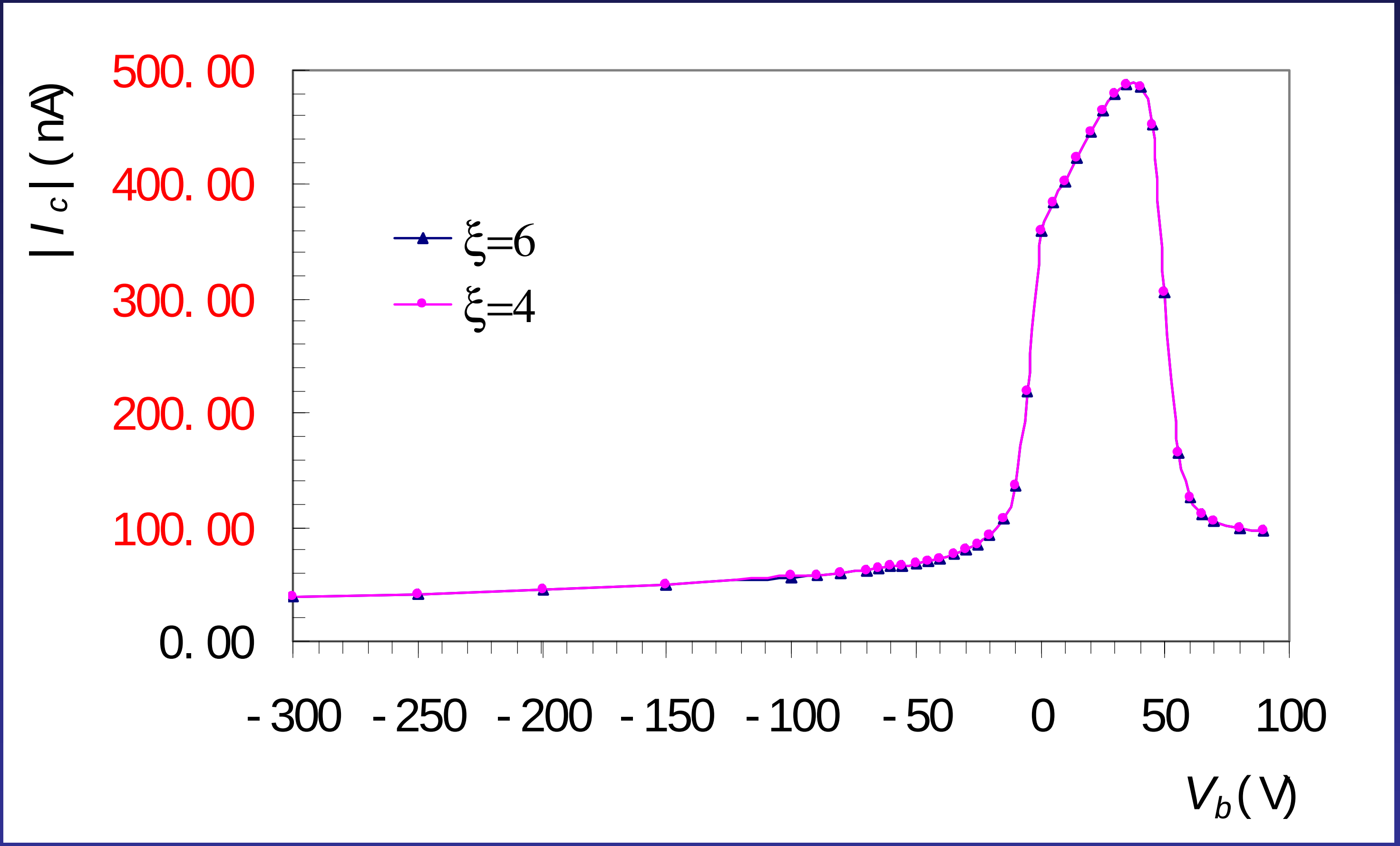


2) Beam energy and emittance



- **Result: The energy and emittance are not sensitive to the I_c.**

3) Chromaticity

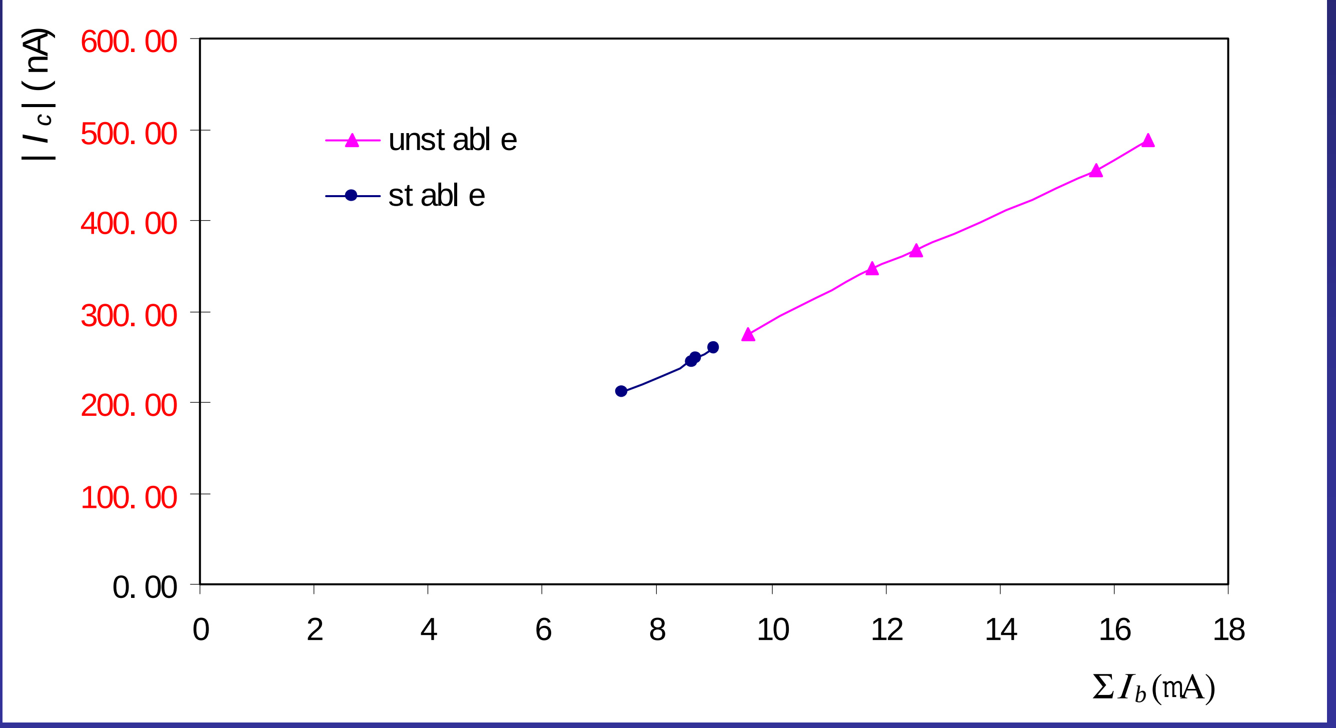


- **Result: The chromaticity is not sensitive to the I_c either.**

4) Stable and unstable beams

- A kind of vertical coupled-bunch instability occurs and a broad spectrum appears for the positron beam at the threshold beam current of 9.7 mA.

- When the total beam current reaches 9.8 mA with 160 bunches uniformly distributed around the storage ring in each bucket, the beam instability occurs as before.

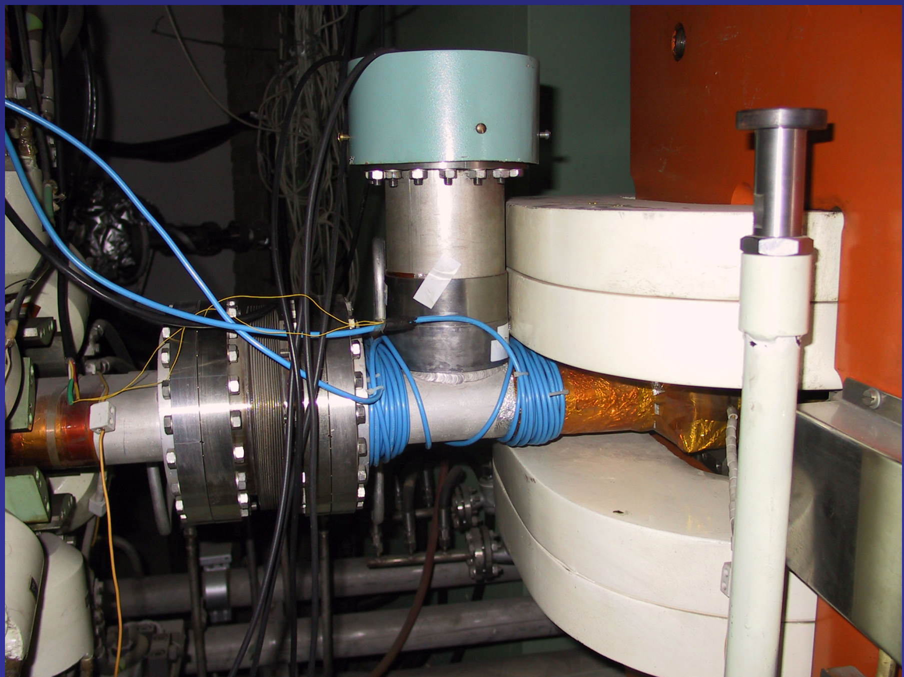


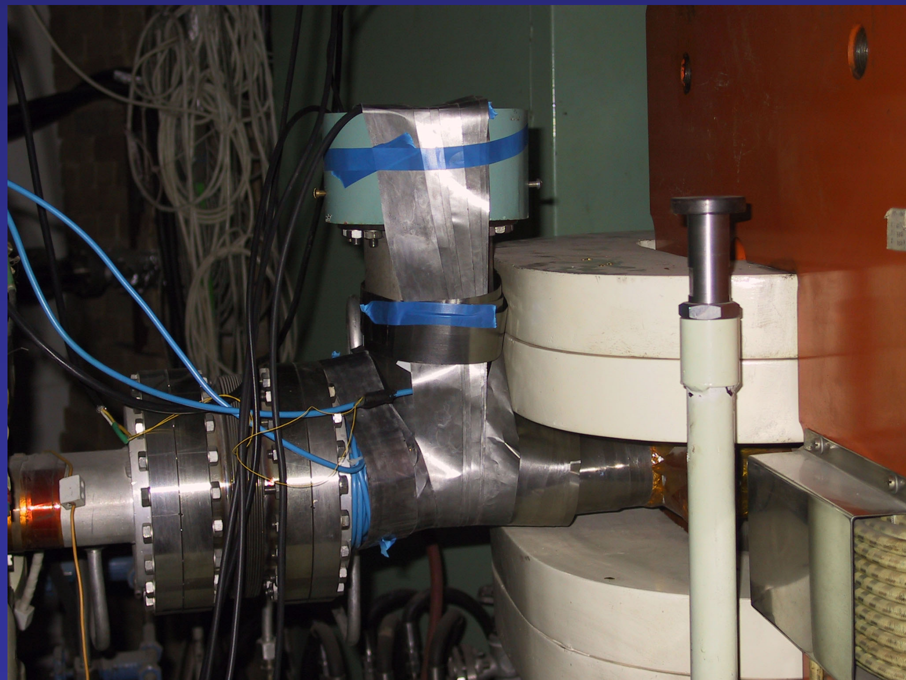
- Result: relations of I_c vs. I_b and normalized I_c vs. V_b have the same regulations under the conditions of stable and unstable beams.

- The instability is also observed with 16.6 mA in 116 bunches, and results of I_c dependences are the same as the single bunch results.

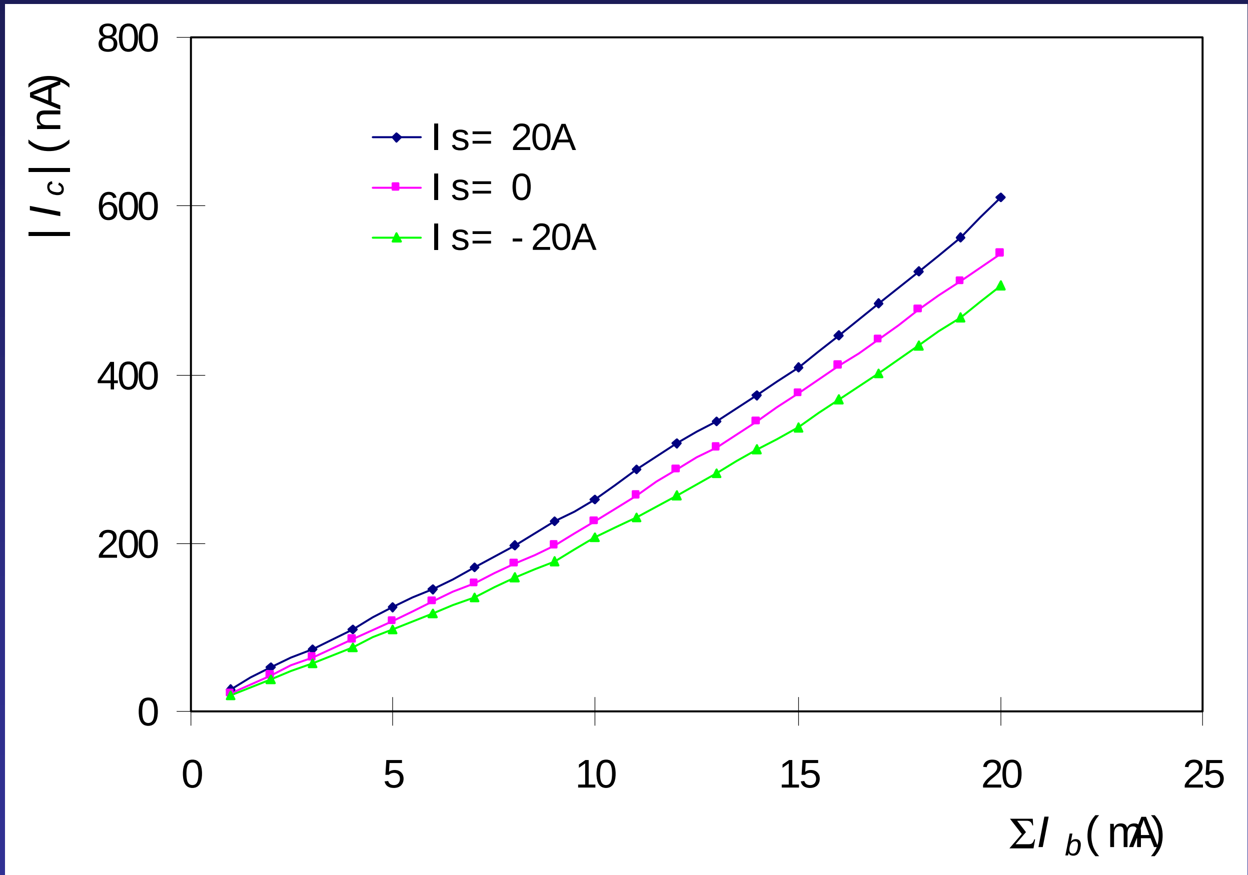
- The beam oscillation due to PEI doesn’t influence the photoelectron yield.

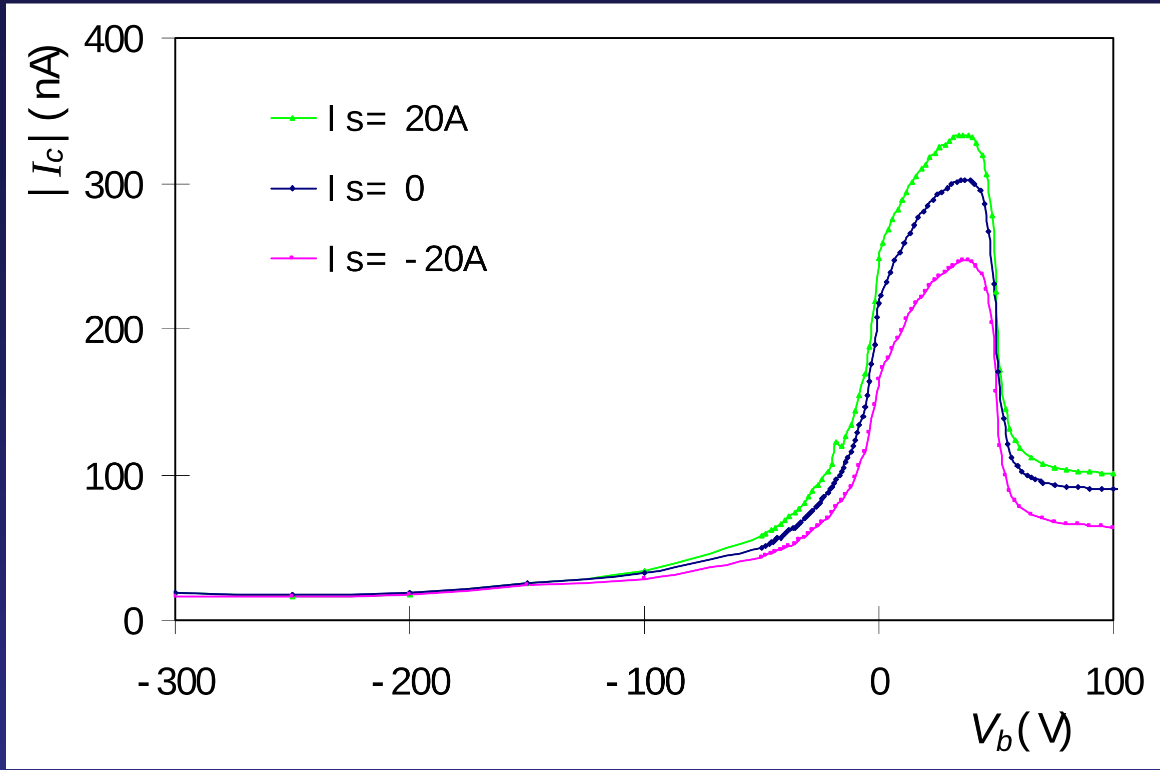
3.5 Solenoid effect





- **The currents of the solenoid coils, I_s, are ±20A, which can generate several tens of Gauss magnetic field.**





- **The solenoid field does influence the electron cloud, but not strong.**

- **The difference when the direction of the solenoid field changes comes from the combining effect of the solenoid field and the fringe field of the bending magnet, which is located near the detector.**

- **The fringe field and the solenoid field inside the chamber have the same order of about 10 to 30 Gauss (measured value).**

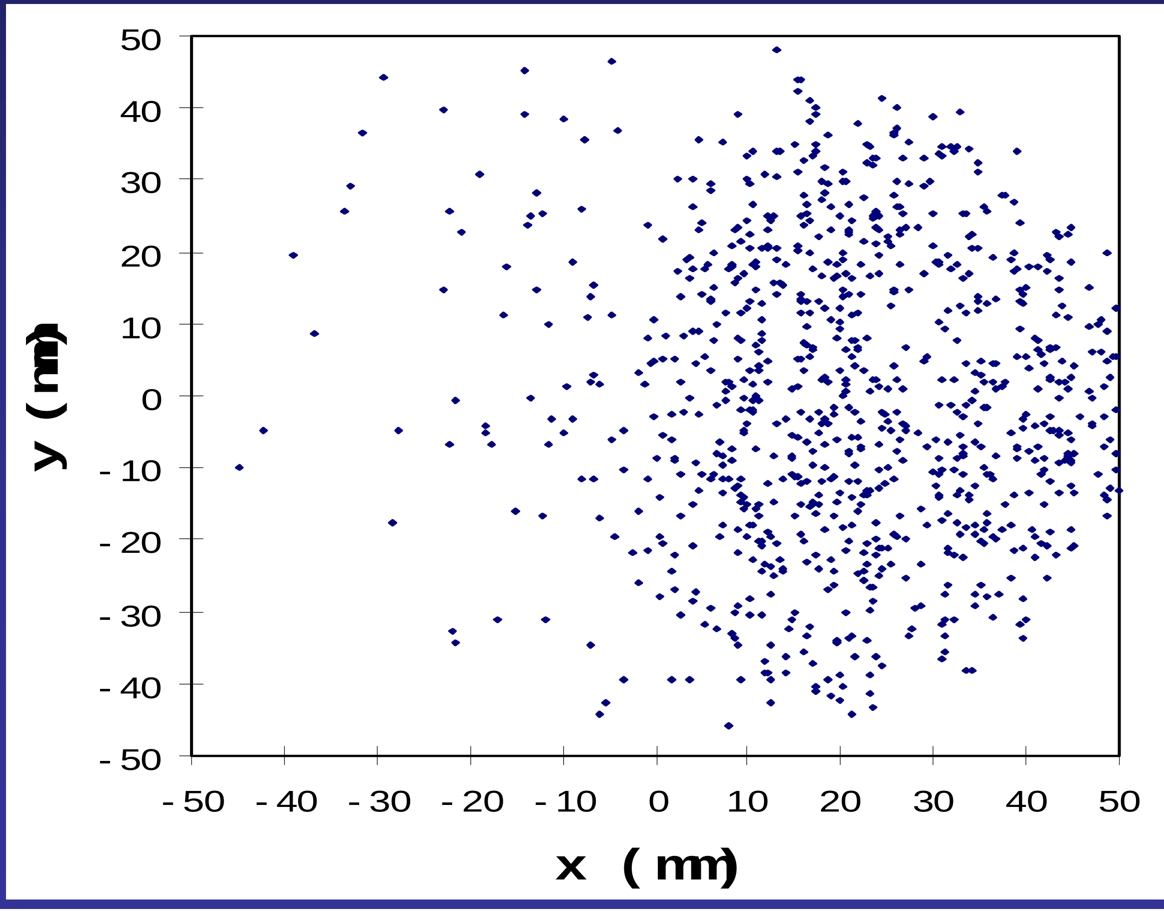
4. Simulations

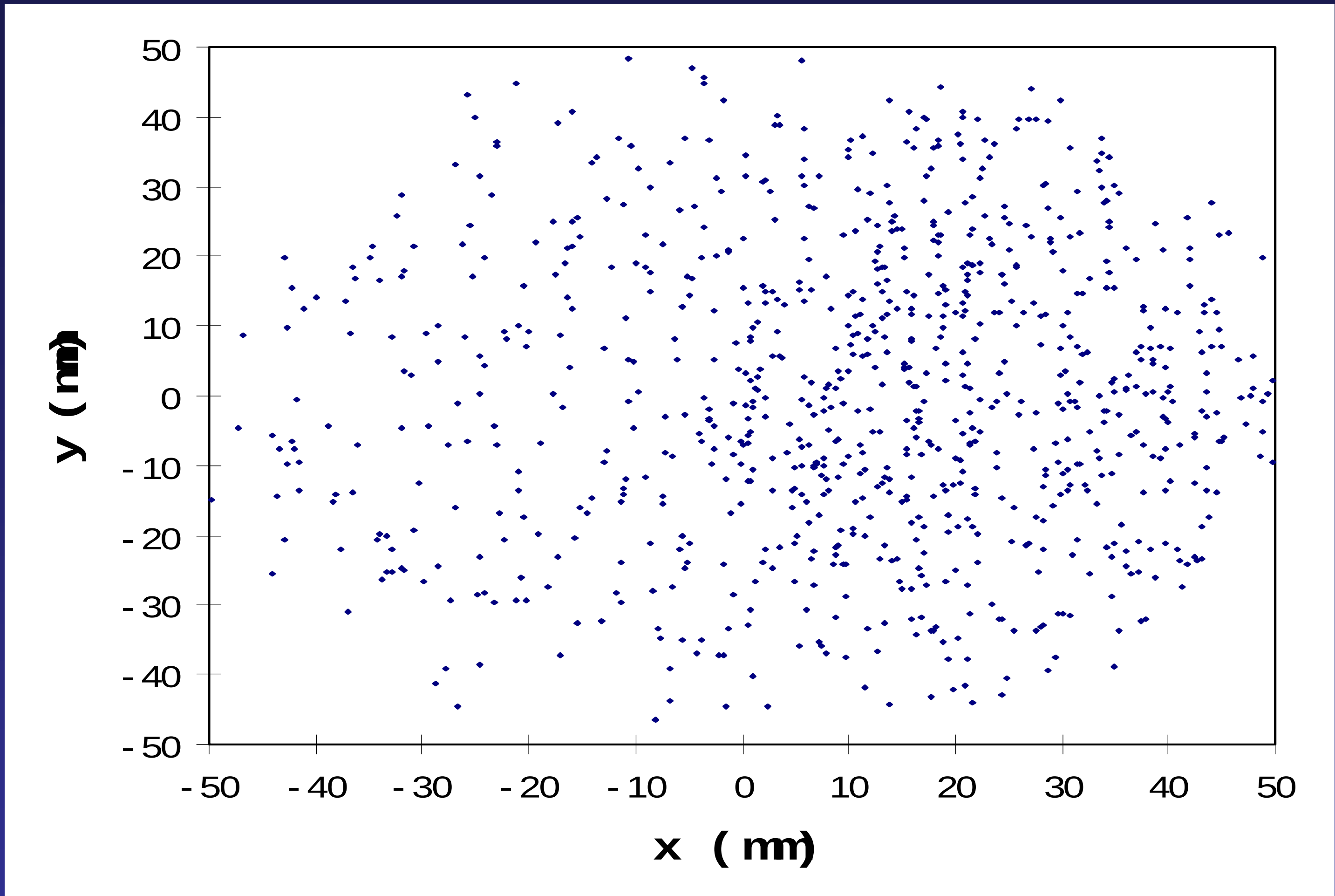
- The creation of photoelectron in the BEPC storage ring is simulated.

- Input parameters for simulations based on the BEPC machine:

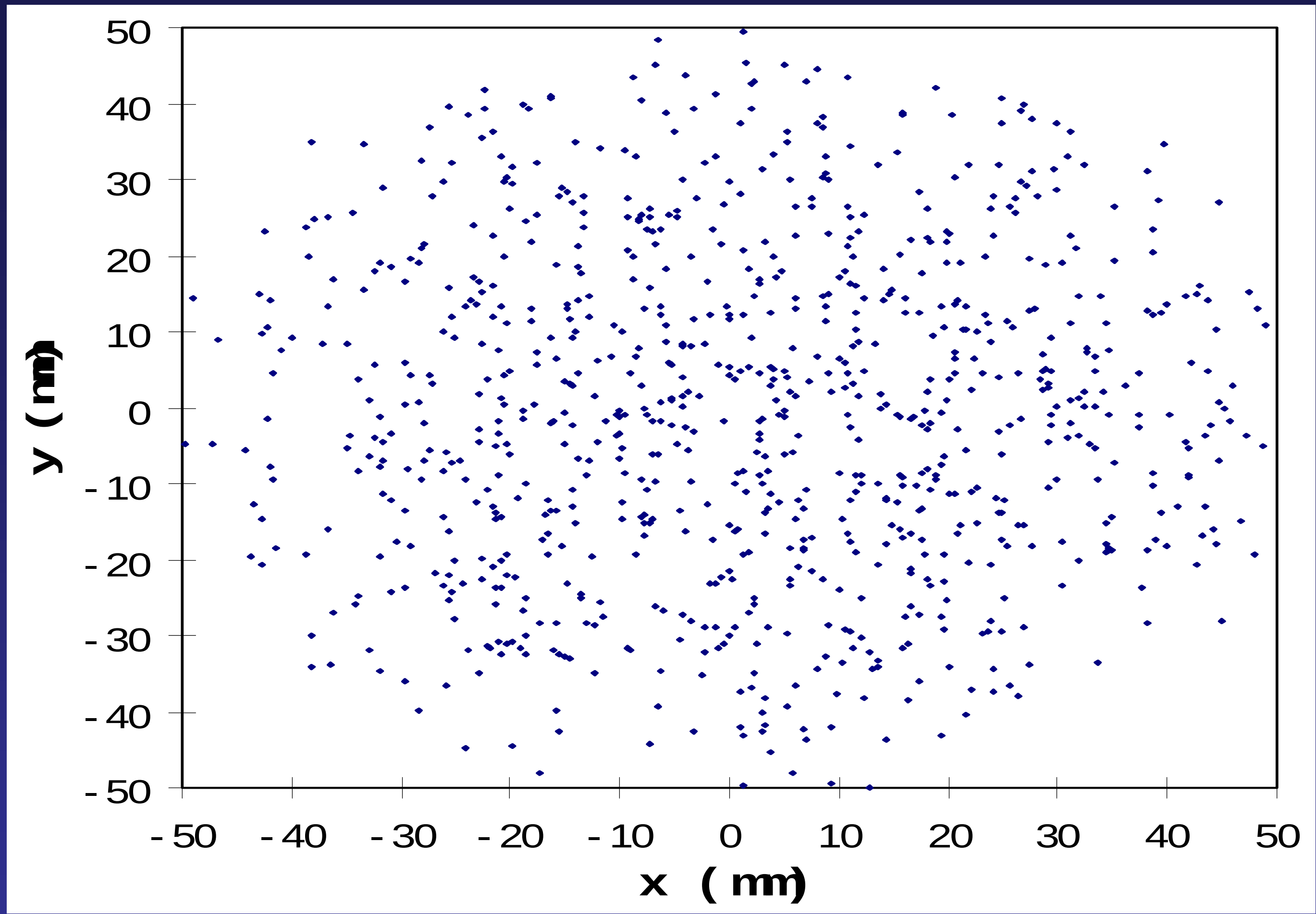
  Al vacuum chamber with an effective radius of r = 50mm.

PE distribution
in transverse
(PE reflectivity=0.1)

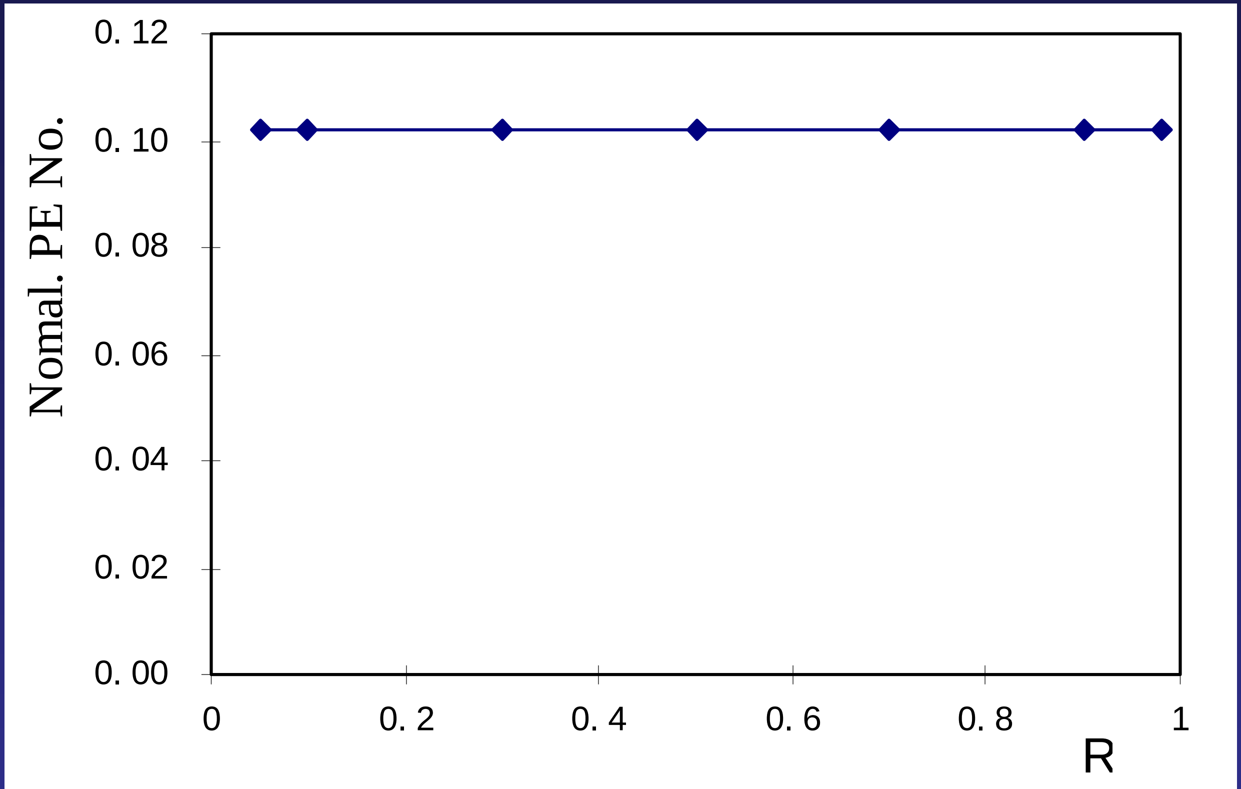




PE distribution in transverse
(PE reflectivity=0.5)



PE distribution in transverse
(PE reflectivity=0.9)



The normalized PE number under different reflectivity

- **Assumptions in simulations**
  - **— Photoelectron yield Y' = 0.1**

    Photoelectron reflectivity R = 0.98

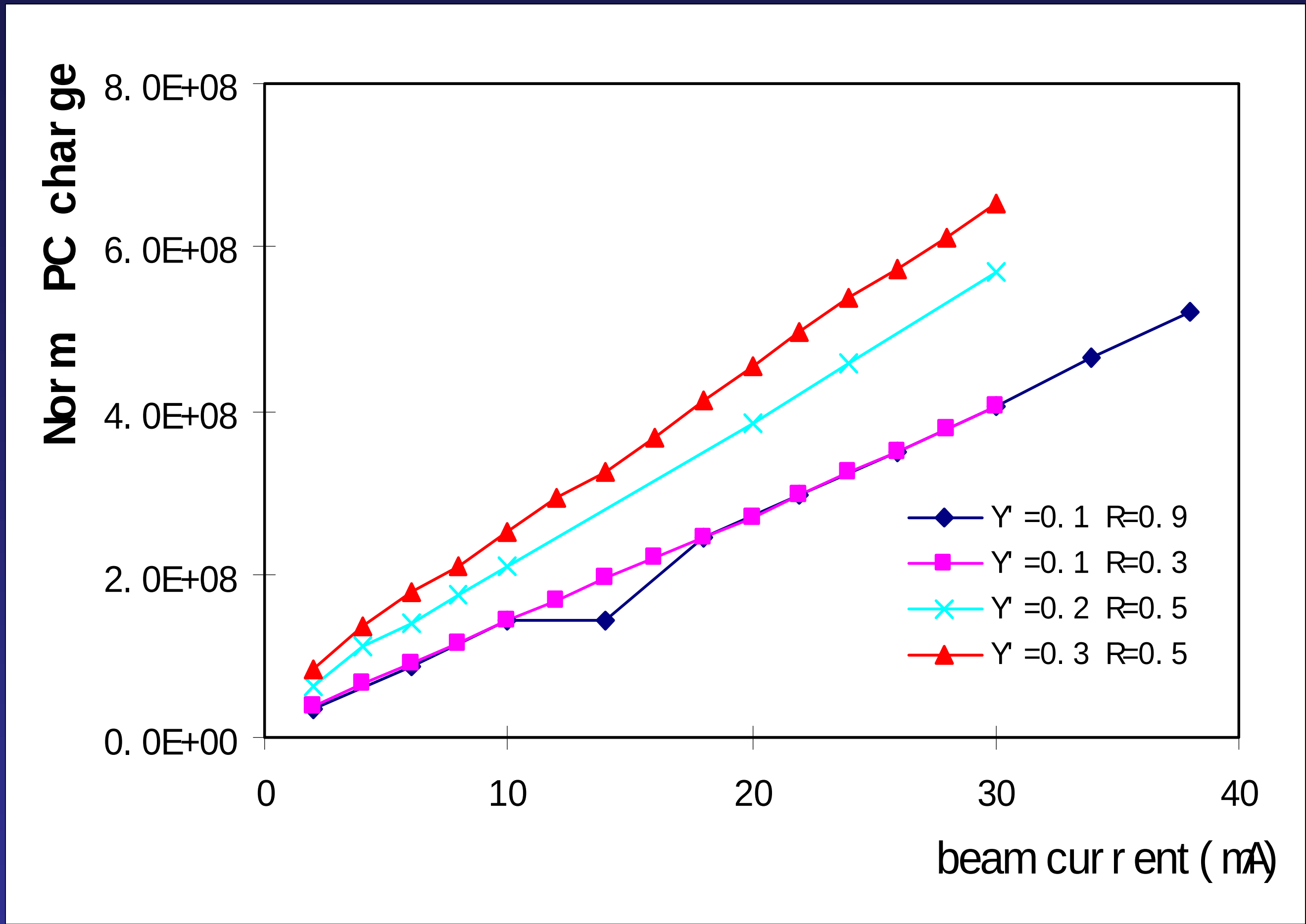
    Energy distribution: 5eV±5eV

    Angle distribution: cosθ distribution
  - **— Secondary electron:**

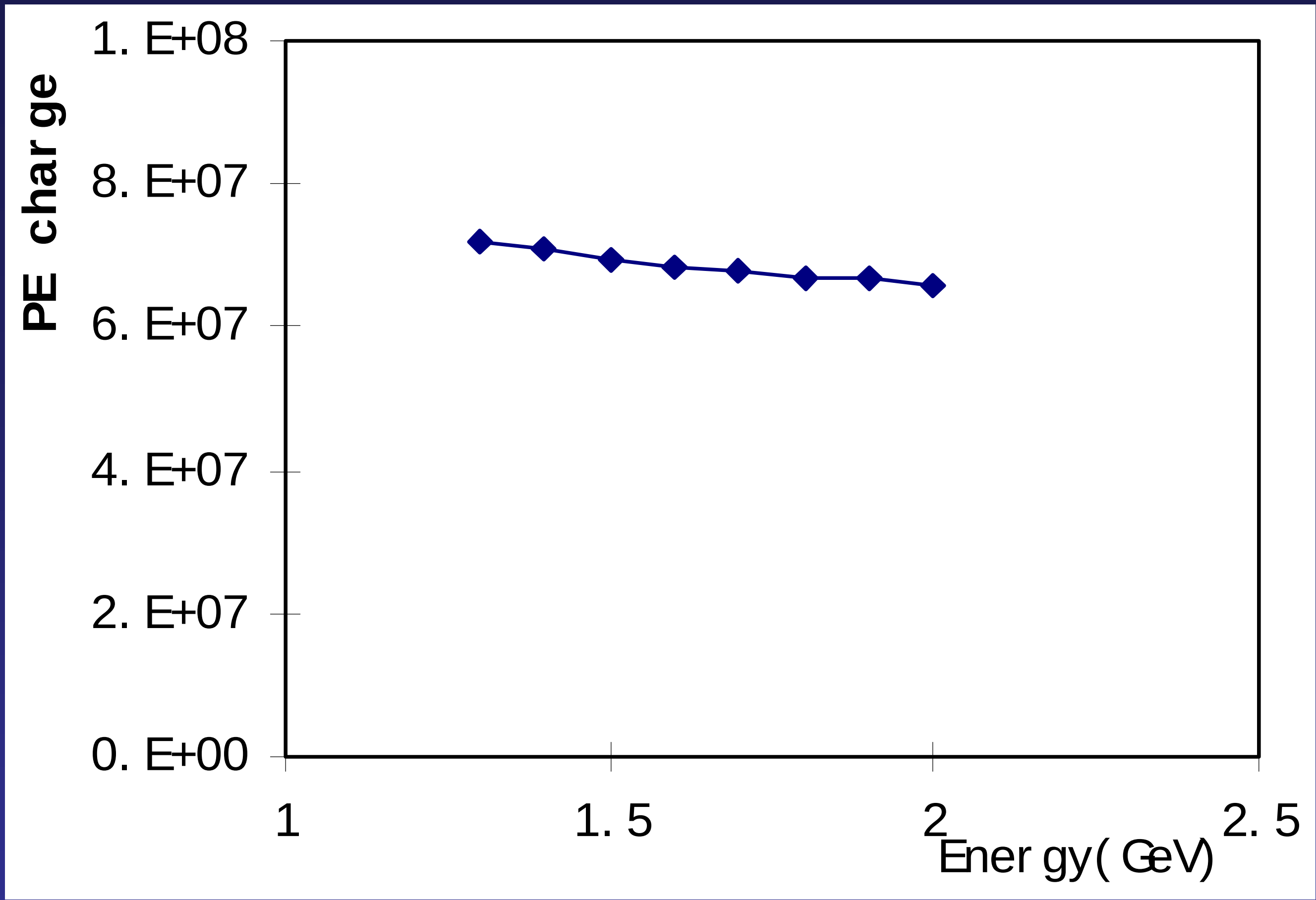
    Emission yield got from

$$\delta(E,\theta) = \delta_{\max} \cdot 1.11 \cdot \left(\frac{E}{E_{\max}}\right)^{-0.35} \cdot \left(1 - \exp\left[-23 \cdot \left(\frac{E}{E_{\max}}\right)^{1.35}\right]\right) / \cos\theta$$

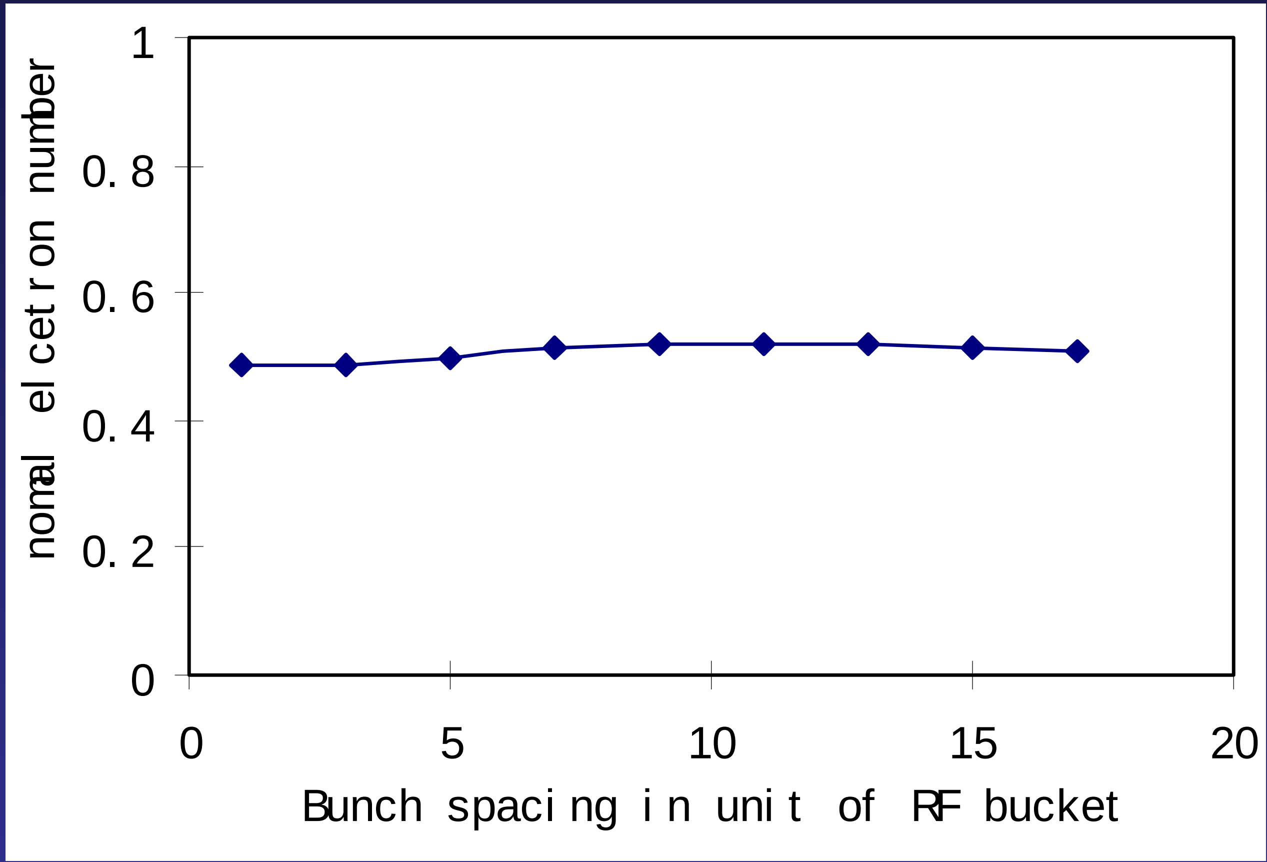
Secondary electron yield: δ_{max} = 1.5, E_{max}= 250eV
Energy distribution: 0eV + 5eV
Angle distribution: cosθ distribution



PE (in unit of electron charge *e*) creation with the increasing beam current. (I_b = 2mA, n_b = 1, 3, 5, 7, … 19.)



PE creation as a function of beam energy
(Single bunch, I_b = 2mA)



Normalized PE number as a function of bunch spacing
(S_b = 5ns, n_b = 5, I_b = 5mA)

5. Discussions

1) **Detailed measurements of the properties of PE cloud were carried out at the BEPC storage ring under various machine conditions for both stable and unstable beams.**

- **Comparisons were made between single and multi-bunch cases as well as for e+ and e– beams.**
- **In most cases, the collector current, I_c, was recorded with a constant retarding voltage, V_b, of +40 V, giving the maximal signal level.**
- **I_c varies linearly with the beam current I_b as expected, since the number of photoelectrons is proportional to the photon intensity and the beam current.**
- **For positron beam I_c/I_b is ~25 nA/mA, while for electron, I_c/I_b ~5 nA/mA. It is same for single and multi-bunch patterns.**

- **There is no saturation process observed up to 40 bunches with 1 or 2 mA/bunch.**

- **Very weak dependence on bunch spacing, using 5 and 10 bunches with 1 to 6 mA/bunch up to the 12-bucket spacing was observed.**

- **No beam-induced multipacting was observed at the BEPC. No significant differences were observed in I_c behaviours for stable and unstable beams.**

2) Simulation studies

- **The number of PE does not change as the PE reflectivity varies.**

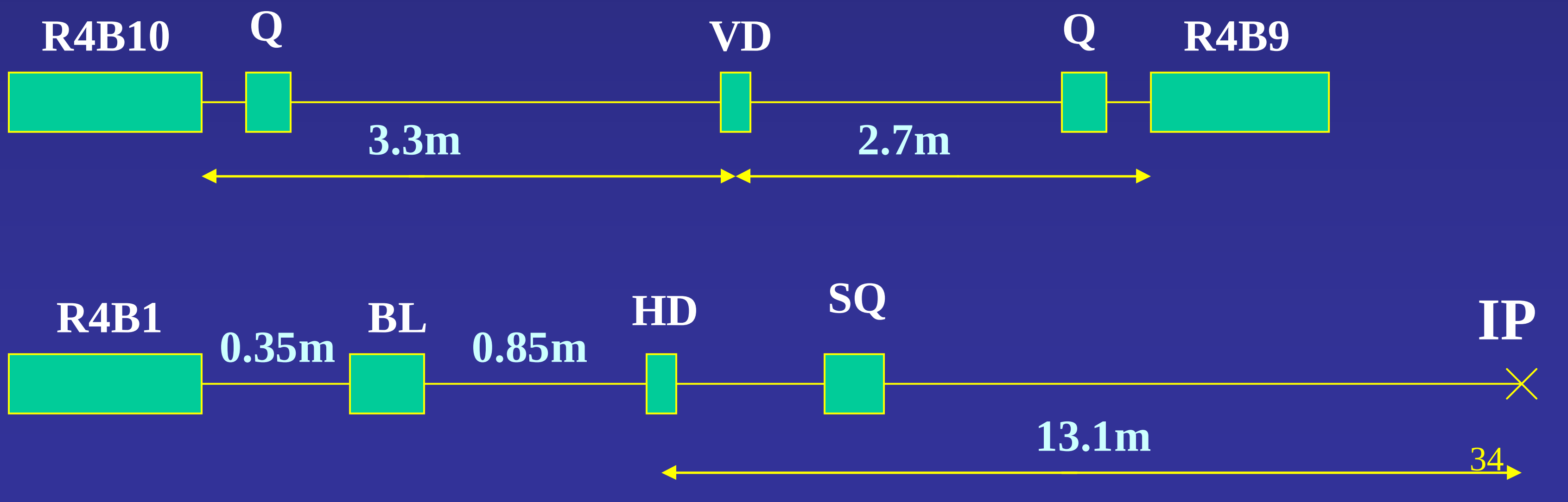
- **The results of the PE creation under different beam current, energy and bunch spacing are consistent with the observations on PE detector.**

3) Further studies

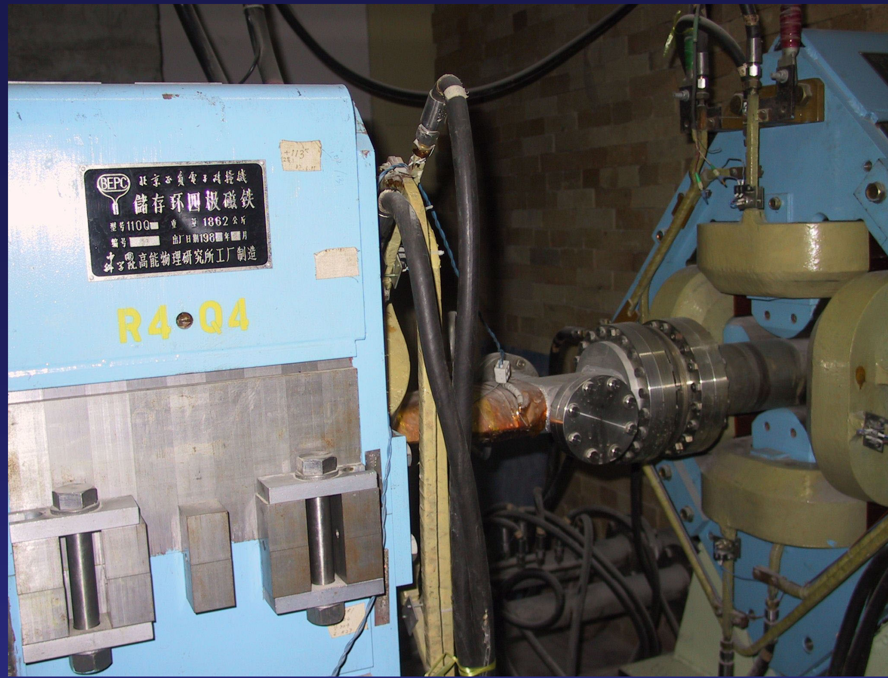
- Two new detectors, modified as encircling the grounded grid but isolated from the retarding grid and the collector, are being manufactured.

- One will be installed with the same orientation as the previous detector, another installed horizontally in the inner ring.

- The distances between the new detector to bends:



Port for vertically-installed detector



Port for horizontally-installed detector

- **The time structure of I_c signal and the machine parameter dependences would be studied further.**

- **Better shielding is necessary on the existing detector to avoid the fringe field of the dipole.**

- **More simulation studies are under way.**

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