Summary of Observation Session.

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Abstract

Here is given a short summary of data presented on "Observation" session on Beam-Beam workshop held at FNAL from June 25 to June 28 2001.

1 INTRODUCTION

Since the beginning of colliding beams era the beam-beam interaction phenomenon attracted much attention because of the role of this phenomenon in colliders performance limitation. Theory developing, numerical simulations and experimental studies in the past decades provided significant progress in understanding of the phenomenon. The most recently built B - factories, PEP-II and KEKB, even though having complicated beam colliding scheme (different colliding beams energies, crossing angle) reached excellent beam-beam performance ($\xi \sim 0.05$) and high luminosity in very short period of time.

However, many features of the beam-beam interaction such as dependence $\xi$ on damping, coupling, machine non-linearity and etc. still are not well understood. Better understanding may lead to a significant progress in efficiency of the existing and future colliders.

One task of the "Observation" session was to review a recently collected experimental data in order to evaluate recommendations which can be useful in future planning.

The data presented on the session came from two low energy lepton colliders VEPP-2M (Novosibirsk) and DAΦNE (Frascati) and from ion-ion collider RHIC (Brookhaven).

2 RECENT BEAM-BEAM OBSERVATION ON VEPP-2M [1]

Three recent experiments were reported from VEPP-2M.

- Dynamic Beta Effect. This effect is in fact distortion of the linear machine optics caused by interaction of one beam particles with an opposite beam. In the study, vertical beam size of weak electron beam collided with strong positron beam was monitored at two different locations along the beam trajectory. The distortion of vertical beta-function was calculated from the change of ratio of beam hights at these locations. Beta function distortion was measured as a function of positron beam intensity for various positron bunch length and beta function at interaction point. Under certain condition, the vertical beta function was changed by a factor two. The experimental data are in good agreement with theoretical model.

- Flip-Flop Phenomenon study was in line with phenomenological models described in references [3], [4] and [5].

- Coherent Synchro-Betatron Beam-Beam Modes study was in line with phenomenological models described in references [3], [4] and [5].

It should be mentioned that even though the effect of linear optics distortion by beam-beam interaction was known for a long time, there were only several documented experimental studies related to this phenomenon, see for example [2]. Thus, the reported data which confirm theoretical model in wide range of parameters is of great significance.

- Flip-Flop Phenomenon study was in line with phenomenological models described in references [3], [4] and [5].

Often in lepton colliders beam-beam interaction causes the equal intensity colliding beams to have very different beam sizes. This effect, called flip-flop phenomenon, may occur when colliding beam intensities exceed the threshold. Like it was done in previous work, the authors assume that the vertical size of one beam is a function of ratio of intensity to vertical size of other beam, i.e., $\sigma_1 = f(l_2/\sigma_2)$. Note that the $l_2/\sigma_2$ is proportional to $\xi_0$ parameter. Using measured dependence of the weak beam vertical size on intensity of strong beam, one can write down the system of two equations and find solution $\sigma_{1,2}(l_1, l_2)$ numerically. In the case of two equal intensity beams $l_1 = l_2 = l$, there will be single solution $\sigma_1(l) = \sigma_2(l)$ for low intensity $l \leq h_r$, and, if function $f$ is steep enough, there will be more then one solutions with $\sigma_1(l) \neq \sigma_2(l)$ for higher intensity, $l \geq h_r$. $l_{th}$ is a threshold current. The multiple solution indicates appearance of the flip-flop effect.

In general, experimental data fit well the model prediction. However, there is good agreement between modeled and measured flip-flop threshold current, but only qualitative correspondence between measured and predicted dependence of vertical beam sizes on beams intensity.

Results of this study confirm that the simple model using beam-beam parameter $\xi_0 \sim l/\sigma$, and weak-strong approximation can only qualitatively describe the dynamics of colliding beams. For more realistic description one should use more complicated model with more parameters involved.

- Coherent Synchro-Betatron Beam-Beam Modes study was another interesting experiment reported from VEPP-2M on this session. In this experiment two synchrotron light monitors with edge screens were aimed on both counter colliding beams. The horizontal edges of the screens were positioned to cut out part of the SR beam images projected on PMT cathode. In this scheme, the signal from PMT was very sensitive to vertical position of the bunches. In the process of measurement, one bunch (there was one bunch per beam) was excited by a short pulse and then signals from both PMTs were recorded on turn-to-turn base. Fourier analysis of the recorded signals reviled the excited modes.

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At least 6 (!) synchro-betatron modes $0\sigma, 1\sigma, 2\sigma$ and $0\sigma, -1\sigma, -2\sigma$ (first index means dipole, quadrupole and etc. distribution in synchrotron space, $\sigma$ and $\pi$ refer to the betatron motion of the bunches) were seen. At low beams intensity ($\xi_\perp < 0.05$) two "classical" $0\sigma$ and $0\sigma$ modes were detected, while at higher intensity ($\xi_\perp > 0.15$) two other modes $-2\sigma$ and $-2\sigma$ were dominating. This observation is in good agreement with the theory developed early in [6] and [7].

Note that linear theory of beam-beam interaction predicts relation between the $\sigma$ and $\pi$ mode tune difference and $\xi$ parameter: $\delta Q_{\pi-\sigma} = C \cdot \xi$ with $C = 2$. Calculation accounting for nonlinearity of beam-beam force and transverse density distribution gives $C \approx 1.4$. This is confirmed by tracking. However, experimental data for $C$ reported from different machines vary from 1 to 2. The reported experiments suggested the explanation of this diversity. On different machines different types of synchro-betatron modes may be observed. Together with synchrotron tunes varying from one machine to another it can explain the observed variation in $C$ value.

Understanding of the relation between the $\sigma/\pi$ modes tune split and $\xi$ may have a great practical importance. The tune split is easy to measure. If one can establish reliable relation between the tune split and $\xi$, then, using correlation between luminosity and $\xi$ ($L = \frac{1}{2\pi^2 B_2 \sigma_{\text{rms}}} \xi$), one can use this measurement for quantitative luminosity monitoring.

3 BEAM-BEAM OBSERVATION ON DAΦNE [8]

DAΦNE is a recently commissioned low energy ($\sim 0.5\text{GeV}$) lepton collider. It started operation in May 1999 and since then is rapidly progressing by doubling luminosity approximately every 6 months. In the report the machine upgrades which provided the beam-beam performance and luminosity enhancement were discussed.

- **Optimization of general machine parameters** such as collision parameters and global coupling shortly after commissioning allowed to reach luminosity $0.2 \times 10^{30}$ cm$^{-2}$sec$^{-1}$ per bunch and $\xi_\perp \sim 0.01$. Further improvement in coupling ($\xi_\perp \sim 0.3\%$) and better working point ($Q_x = 5.15/5.10, Q_y = 5.21/5.14$ for $e^+e^-$ beams) resulted in luminosity doubling, $L \sim 0.5 \times 10^{31}$ cm$^{-2}$sec$^{-1}$ per bunch.

- **Cubic machine nonlinearity** attracted attention after the strong octupole-like component was detected in wigglers. That promoted intensive study of influence of machine cubic nonlinearity on the machine beam-beam performance.

Early it was found that the topology of the phase space resulted from beam-beam interaction is very sensitive to sign and value of machine cubic nonlinearity [9]. Changing the dependence of tune on amplitude the machine cubic nonlinearity can increase or decrease the width of resonance islands generated by beam-beam interaction. It results in growing or in diminishing of beam tails effecting beam life time.

Numerical simulation made for DAΦNE showed the dramatic effect of the cubic nonlinearity generated in wigglers on particle density distribution in the beam tails. A new optics with reduced beta function in the wiggler locations was designed and implemented to decrease the machine cubic nonlinearity. It helped to improve beam-beam performance, $\xi_\perp \sim 0.02$, and provided luminosity growth, $L \sim 1.0 \times 10^{30}$ cm$^{-2}$sec$^{-1}$ per bunch. The future plans call for octupole lenses installation for better control of machine cubic nonlinearity.

The beam-beam experience obtained on DAΦNE proved the importance of the machine cubic nonlinearity control and demonstrated that the cubic nonlinearity tuning may lead to substantial gain in luminosity and beam-beam performance.


In the report presented by Wolfram Fisher, Relativistic Heavy Ion Collider (RHIC) was described as a potential test bench for future hadron colliders such as LHC and VHLC. Flexibility in manipulation with beams in longitudinal and transverse spaces together with well developed beam diagnostics make possible to study many features of beam-beam phenomenon. Although the time available for the study is limited because of strong competition with other programs, RHIC team is very interested and ready to test new theories of beam-beam interaction.

5 CONCLUSION

Many interesting observations of beam-beam phenomenon were reported on the session. Two of them, observation of coherent synchro-betatron modes on VEPP-2M and dependence of beam-beam performance and luminosity on machine cubic nonlinearity observed on DAΦNE (similar were reported in [10]) are of especial importance and it is very desirable to carry out analogous experiments on other machines.

6 REFERENCES


[8] M. Boscolo on behalf of the DAΦNE team, Beam-Beam Experience at DAΦNE, These proceedings.

