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PHASE DIFFERENCE BETWEEN COLLIMATORS IN A COLLIDER

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1. INTRODUCTION

In view of the design of an efficient collimation system for LHC, some experiments are going on in the pbar-p collider. There is also a need for improving the present situation for UA2 with the new low-beta insertion, which is more critical in terms of acceptance at beta-max in the insertion. Also, the UA4' project requires an improved system of collimation.

A first estimation of the impact parameters of halo particles on the primary collimator has been done in 1989 (Ref. 1).

The next step is to compute and measure the efficiency of the combination of a primary and a secondary collimator, separated by a certain phase advance.

The aim of this note is to define the best phase advance between the two collimators. Until now, the rule was to choose $\Delta\psi = 90°$ (Ref. 2). This principle is revisited.

2. THE CASE $\Delta\psi = 90°$

If two points S1 and S2 along the beam line in the collider are separated by $\Delta\psi = 90°$ the linear transfer matrix $M(s_1,s_2)$ (Ref. 3) is simple because $\alpha_1 \approx \alpha_2 = \alpha$, $\beta_1 \approx \beta_2 = \beta$ and $\cos(\Delta\psi) = 0$, $\sin(\Delta\psi) = 1$:

$$M(S_1, S_2) = \begin{pmatrix} \alpha & \beta \\ -\dfrac{1+\alpha^2}{\beta} & -\alpha \end{pmatrix}$$

A particle hitting the first collimator (C1 at s_1) which has a jaw placed at x_0 from the beam axis has the phase space coordinates

$$\vec{x}_1 = \begin{pmatrix} x_0 \\ -\dfrac{\alpha}{\beta} x_0 \end{pmatrix} \quad \text{from which } \vec{x}_2 = M\,\vec{x}_1 = \begin{pmatrix} 0 \\ -\dfrac{x_0}{\beta} \end{pmatrix}$$

This means that if no kick is applied in C1, that particle will be on the beam axis at C2, and will, of course, not be absorbed there. Let us now compute which kick must be applied to get $x_2 > x_0$; assuming that the jaw of C2 is also placed at x_0 from the beam axis (the best case). We define

$$\vec{x}_{1\delta} = \begin{pmatrix} x_0 \\ -\dfrac{\alpha}{\beta}\, x_0 + \delta \end{pmatrix} \quad \text{and compute } \vec{x}_{2\delta} = M\, \vec{x}_{1\delta} = \begin{pmatrix} \beta\delta \\ -\dfrac{x_0}{\beta} - \alpha\delta \end{pmatrix}$$

The condition becomes $x_2 > x_0$ becomes $\beta.\delta > x_0$ or $\delta > x_0 / \beta$. If

$$x_0 = 6\sigma = 6 \bullet \frac{1}{2} \bullet (\beta \bullet \varepsilon)^{1/2} \quad \text{then } \delta > 3 \bullet (\varepsilon/\beta)^{1/2}$$

If $\beta = 50$ m (corresponding to the position of the present TAL119) and $\varepsilon = 057$ pi.mm.mrad then $\delta > 0.1$ mr. Below, ε shall always be given in pi.mm.mrad.

This is also approximately the average kick given to the protons which survive after the passage through the collimator primary and which are send back into the acceptance.

To illustrate better what happens, a simple simulation was done, in which protons with initial conditions $x_0 = 6\ \sigma$, $x' = -(\alpha/\beta) \bullet x_0$, $y_0 = 0$ and $y_0' = 0$ at C1 where applied an angular kick dx' uniformly distributed between -.2 < dx' < .2 mrad. They were then transported to C2 ($\Delta\psi = 90°$). This is illustrated on Figure 1, together with the phase-space ellipse of emittance ε' corresponding to $x_0 = 6\ \sigma$, i.e. $\varepsilon' = (1/4)\ (n_{sigma})^2 \bullet \varepsilon = 0.513$. The protons lying beyond the point A on the jaw of C2 are absorbed by C2, while those lying on the right of A will stay in the machine. The unabsorbed fraction of those protons have an emittence in the range $\varepsilon' < e_{halo} < 2\ \varepsilon'$, which means that a secondary halo will fly in the acceptance between $6 < n_{sigma} < 10$. The limit of 10 σ is precisely that one at which the XPOT are starting to disturb the other collider experiments. This is also the limit of acceptance in the QWL's at the pole tip.

3. EXPLORE OTHER PHASE DIFFERENCES

The extreme case to study is $\Delta\psi = 180°$, for which $\alpha_1 \approx \alpha_2 = \alpha$, $\beta_1 \approx \beta_2 = \beta$ and cos ($\Delta\psi$) = 1, sin ($\Delta\psi$) = 0. It follows that

$$M(S_1, S_2) = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$$

This means that all particles touching C1 without being absorbed by it have at C2 the position $x_2 = x_0$, independent of dx' (see also Figure 2). As C2 must have a slightly recessed position relative to C1 in emittance units (otherwise it would be the primary collimator) a phase difference of $\Delta\psi = 180°$ is not a good solution.

In between, the case $\Delta\psi = 135°$ is also explored. The result of the simulation is shown in Figure 3. We see that the contributions of x and x' at C1 do not cancel too much while building x at C2. In that case, the emittance not caught by C2 is $\varepsilon' < \varepsilon_{halo} < 1.2 \bullet \varepsilon'$. This implies that the secondary halo is flying in the region $6 < n_{sigma} < 6.6$ sigma. This is a much sharper cut than in the case $\Delta\psi = 90°$. We also see that contrary to the $\Delta\psi = 180°$ case, the impact parameter on C2 is quite good. The scale is in millimeters, which means an almost total absorbtion.

We can get an even better case by choosing a phase difference closer to 180°, which decreases further the range of unabsorbed emittance, while keeping good impact parameters. Finding the optimum $\Delta\psi$ between 135° and 180° will require a detailed and quantitative study. Practical considerations shall be also taken into account.

4. FURTHER CONSIDERATIONS

- In that study, we assumed that both C1 and C2 have their jaws aligned with the halo at their working positions, i.e. $x' = -(\alpha/\beta) \bullet x_0$. This implies that the jaws should not be aligned with the beam axis but rather with x'. At least for C1, where impact parameters are small, the jaw angle must be adjusted at run time. Two prototypes of such collimators are presently under construction with that property.

- On all the figures, one branch of the halo is shown with an interrupted line, corresponding to dx' > 0 at C1. That branch, for dx' > 0, is assumed to be almost absorbed in C1. This is true only for a sufficiently long jaw and a very good angular alignment. Otherwise an additional collimator shall be installed at a phase difference between 10° and 20° after C1 to absorb that branch.

- The implications due to the separation of the two beams in the collider are not discussed here.

- Other improvements are still possible by choosing a large b value for C1 and C2, in order to maximise the term m_{12} of the transfer matrix. This stretches the halo branch and so decreases the density of particles in the fraction of the emittance kept in the acceptance

5. CONCLUSIONS

New rules are proposed for improved collimation in the collider, which shall also serve to a first approach of the collimation in the LHC. The most important parameter is the phase difference between two collimators, which shall lie between 135° and 180°.

While many practical considerations remain to be explored for both machines, the potential seems to be there for an efficient collimation scheme. A quantitative analysis aiming at efficiency computations can now be started.

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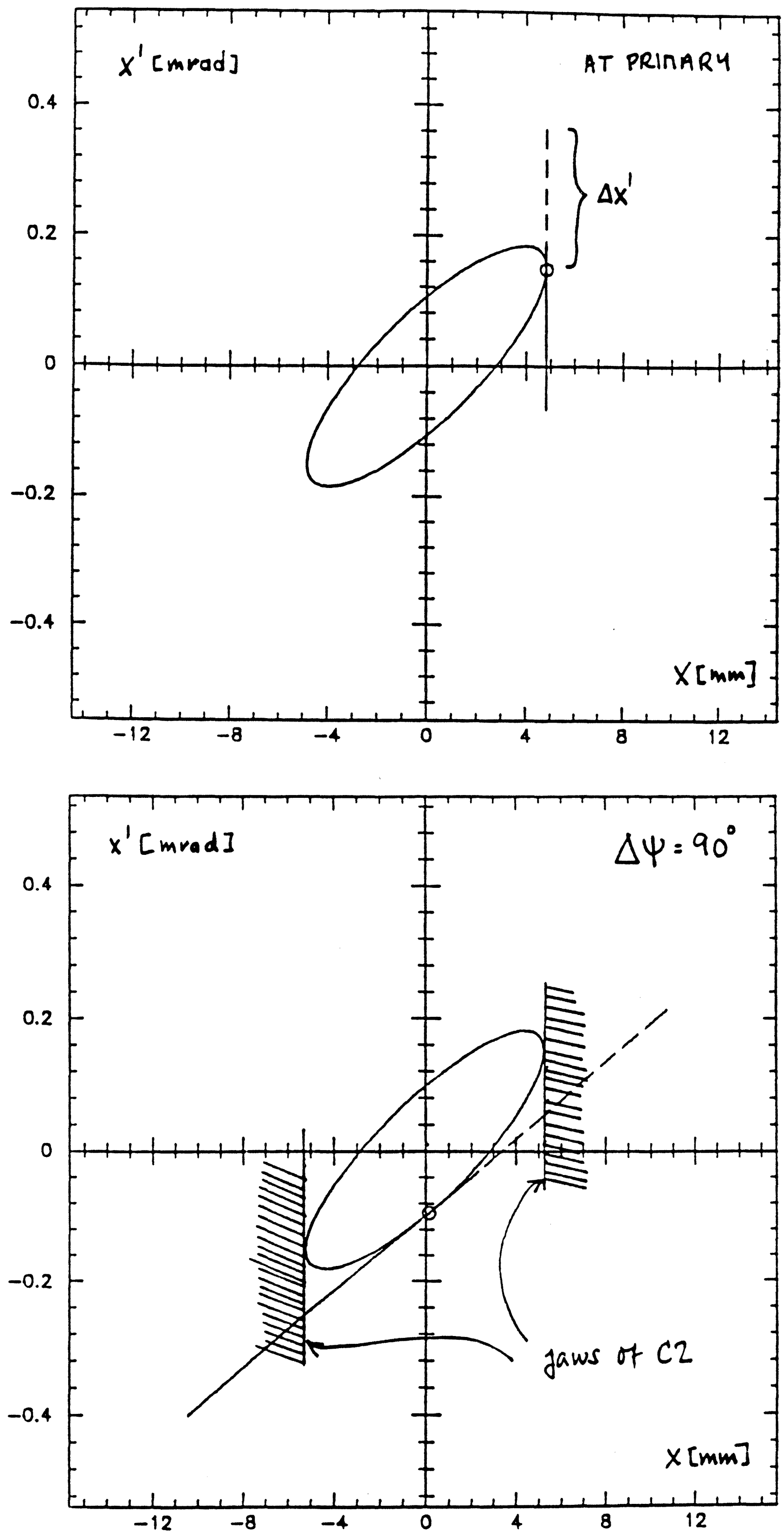

Figure 1 : The phase-space ellipse at 6σ and the halo branches ($\Delta x' = \pm 0.2$mr) at the primary collimator (top) and at the secondary one placed at a phase advance of $\Delta\Psi = 90°$ (bottom).

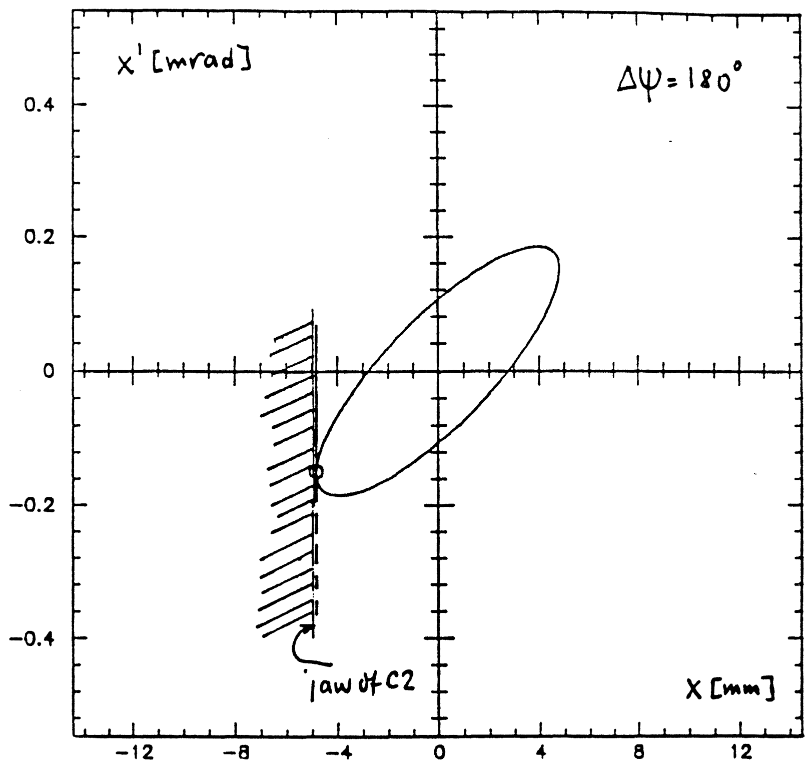

Figure 2 : As figure 1, but for $\Delta\Psi = 180°$.

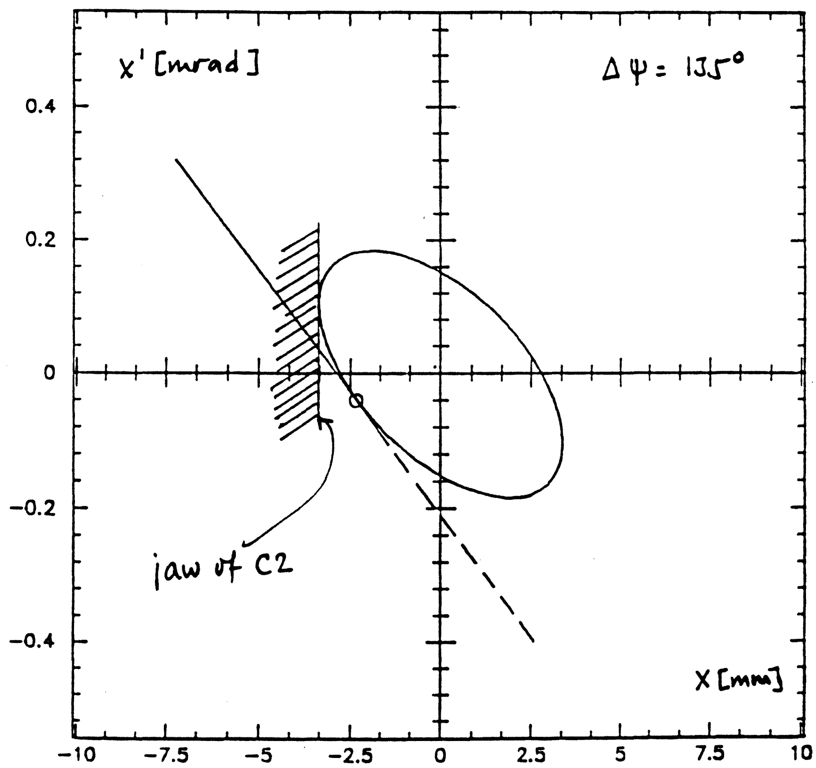

Figure 3 : As figure 1, but for $\Delta\Psi = 135°$.