Summary of the collimation working group at the ICFA-7 meeting

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The topics discussed were:

1. Comparison of different collimation methods (efficiency, design and engineering);

2. Momentum collimation and how to catch particles lost during rf capture and those due to large dp/p;

3. Location of collimators: requirements, dedicated sections, adaptation to an existing lattice.

The machines discussed were the proposed high intensity proton synchrotrons: ESS in Europe and SNS in Oakridge - neutron sources, the JHF booster, the 16 GeV Proton Driver as first stage of a $\mu\mu$-collider and the LHC. Among the operating machines: the Tevatron and the ISIS synchrotron.

For the needs of this working group, *collimation efficiency* was defined to be the fraction of beam halo particles collected within the collimation section during multiturn operation, relative to the total number of particles lost around the ring (relative controlled particle loss). One needs exact counts for absorption and outscatter, hence Monte Carlo simulations are required with high demands on precision – several such codes were reported: STRUCT–MARS, K2, the code of C. Warsop. Efficiency near or above 99% over $10^2 - 10^3$ turns is usually aimed for, as well as low halo hit rates (particles/sec) at crucial locations around the ring such as secondary collimators, cold elements and particle detectors.

The advantage of the *two-stage scheme* compared to the single collimator was acknowledged – particles backscattered from the latter continue to circulate. Comparative simulation studies (Tevatron Run II) give a factor of 4-10 in beam loss.

As far as lattice permits, the betatron phases of collectors with respect to scatterer are chosen according to the "$\mu, \pi/2, \pi-\mu$" scheme, with the $\pi/2$ collimator sometimes missing (see below). Derivation of the above phases is based upon the "black absorber" model: 1) single passage; 2) artificially wide distribution of initial angles at primary; 3) "black-absorber" secondaries. The advantage is that efficiency can be redefined in terms of the maximum surviving halo amplitude (a number) and numerical minimization applied. This model has been explored beyond single-plane collimation (mostly for the needs of LHC; works of J.B. Jeanneret et al). Some recent results were reported (D. Kaltchev) – the code DJ (Distribution of Jaws) provides optimization of jaw locations and angles for an arbitrary lattice (phase-advance and dispersion functions). The underlying assumption is that a high one-passage "black absorber" efficiency means also a high multi-turn Monte Carlo efficiency. The latter is the final criterion in any case. Some deviations from the "black absorber" optimum solution, presumingly due to the multiturn definition of efficiency, are

– using a single instead of double-jaw collimator. This seems to be more a rule than exception. For a single jaw, the average impact depth over many turns is higher. Also, it allows to collimate particles with selected sign of the momentum deviation (negative, i.e. low energy side for the Tevatron). In the double-jaw case, having independent position control of the opposing jaw would help finding the closed orbit in realistic operation.

– most systems are designed separately in the horizontal and vertical planes. In some cases small tilt angles are applied (9 degrees in the ESS study). An optimization aiming to capture in a single passage the halo particles with large betatron amplitudes in both planes (jaw tilt angles varied too), is carried out in the LHC design.

– orthogonal scattering is sometimes neglected. Neglecting the $\pi/2$ jaw is justified if scattering orthogonal to the plane of collimation is not taken into account. The third collimator helps in the SNS hybrid lattice (N. Catalan), with computations done for both black and realistic secondaries.

– deviations of around 10% from the phases "$\mu, \pi/2, \pi-\mu$" do not affect significantly the tracking results (ESS accumulator and most other designs).

Full optimization studies were presented (A. Drozhdin, N. Mokhov) of the Tevatron Run II and of the preliminary lattice for the 16 GeV Proton Driver. This included graphs of particle losses around the rings (W/m) computed with MARS. More than 99% of losses are collected at top energy.

Direct experimental confirmation of the two-stage scheme was reported by Nuria Catalan – the 120 GeV SPS beam is made to coast towards a system of scatterer and two collectors, arranged so that all halo fractions are accounted for. The measured rates agree with simulations (K2 code).

One could further notice, that the efficiency is related to parameters such as average impact depth and number of revolutions between hits. Such results were discussed on this workshop – Tevatron Run II, ESS accumulator (C. Warsop) and had been reported previously – HERA (M. Seidel), LHC (T. Risselada) and others. The impact parameter depends on proximity to resonances (for a linear machine) and on the collimator arrangement – for instance larger number of primary collimators means that fewer turns are needed to achieve the same efficiency, but also smaller impact depth.

The shape of collimators used is: (in transverse direction) flat, "L"-shaped with independent hor./vert. degrees of freedom (Tevatron); slightly angled (ESS accumulator study); fully angled (LHC) and (in longitudinal direction) set back with respect to the beam envelope, with a slope to match the beam envelope (Tevatron Run II).

The *bent crystal* shows promising results with respect to lifetime and cost and the expressed concerns were mostly about the introduced by the crystal angle spread in a multi-turn operation. Halo extraction with an *electrostatic deflector* was successfully tried in the $\mu\mu$-collider design. Magnetized collimators were not discussed.

For *momentum collimation* a ring lattice location with high dispersion is needed for the primary collimator. Exceptions (ways to avoid this) are the beam-gap kicker foreseen at SNS and placing the scatterer in a curved transport channel (ESS accumulator). In a dedicated lattice with dispersless straight sections, the ideal primary location seems to be the highest point of the last dispersion peak before the straight section (as in the JHF 3GeV Booster, Y. Mori). In the last work, a flat-top dispersion peak is achieved by splitting the focusing quadrupole in the last "missing magnet" cell. In general, space limitations in the arc and difficulties in increasing the dispersion in the straight section, force us to search for compromises.

D. Kaltchev presented a mix of theory, on which the code DJ is based, and observations made during distributing jaws for the LHC – the advantages of placing the primary jaw at the highest point of the normalized dispersion peak (zero derivative) are: 1) more amplitude space is left for halo circulation at high momenta; 2) secondary collimators act the same way for all momenta (known result). The code DJ provides mixed betatron-momentum optimization of the jaw locations for an arbitrary lattice.

An important remark (A. Drozhdin) was about the benefit of placing the secondary jaw in a location with high dispersion as well, if such location is available.