12.10. Radiation levels in detectors at hadron colliders

An SSC Central Design Group task force made a study of radiation levels to be expected in SSC detectors [50]. Its model assumed

- The machine luminosity at $\sqrt{s} = 40$ TeV is $\mathscr{L} = 10^{33}$ cm^{-2}s^{-1}, and the pp inelastic cross section is $\sigma_{\rm inel} = 100$ mb. This luminosity is effectively achieved for 10^7 s yr^{-1}. The interaction rate is thus 10^8 s^{-1}, or 10^{15} yr^{-1};
- All radiation comes from pp collisions at the interaction point;
- The charged particle distribution is (a) flat in pseudorapidity for $|\eta| < 6$ and (b) has a momentum distribution whose perpendicular component is independent of rapidity, which is taken as independent of pseudorapidity:

$$\frac{d^2N_{\rm ch}}{d\eta dp_\perp} = H\ f(p_\perp) \tag{12.26}$$

(where $p_\perp = p\sin\theta$). Integrals involving $f(p_\perp)$ are simplified by replacing $f(p_\perp)$ by $\delta(p_\perp - \langle p_\perp\rangle)$; in the worst case this approximation introduces an error of less than 10%;
- Gamma rays from π^0 decay are as abundant as charged particles. They have approximately the same η distribution, but half the mean momentum;
- At the SSC ($\sqrt{s} = 40$ TeV), $H \approx 7.5$ and $\langle p_\perp\rangle \approx 0.6$ GeV/c; assumed values at other energies are given in Table 12.7. Together with the model discussed above, these values are thought to describe particle production to within a factor of two or better.

It then follows that the flux of charged particles from the interaction point passing through a normal area da located a distance $r_\perp$ from the beam line is given by

$$\frac{dN_{\rm ch}}{da} = \frac{1.2\times 10^8\,{\rm s}^{-1}}{r_\perp^2}\ . \tag{12.27}$$

In a typical organic material, a relativistic charged particle flux of 3×10^9 cm^{-2} produces an ionizing radiation dose of 1 Gy, where 1 Gy $\equiv$ 1 joule kg^{-1} (= 100 rads). The above result may thus be rewritten as dose rate,

$$\dot{D} = \frac{0.4\ {\rm MGy\ yr}^{-1}}{(r_\perp/1\ {\rm cm})^2}\ . \tag{12.28}$$

If a magnetic field is present, "loopers" may increase this dose rate by a factor of two.

In a medium in which cascades can develop, the ionizing dose or neutron fluence is proportional to $dN_{\rm ch}/da$ multiplied by $\langle E\rangle^\alpha$, where $\langle E\rangle$ is the mean energy of the particles going through da and the power α is slightly less than unity. Since $E \approx p = p_\perp/\sin\theta$ and $r_\perp = r\sin\theta$, the above expression for $dN_{\rm ch}/da$ becomes

$$\text{Dose or fluence}^* = \frac{A}{r^2}\cosh^{2+\alpha}\eta = \frac{A}{r^2\sin^{2+\alpha}\theta}\ . \tag{12.29}$$

The constant A contains the total number of interactions $\sigma_{\rm inel}\int\mathscr{L}dt$, so the ionizing dose or neutron fluence at another accelerator scales as $\sigma_{\rm inel}\int\mathscr{L}dt\,H\,\langle p_\perp\rangle^\alpha$.

The dose or fluence in a calorimeter scales as $1/r^2$, as does the neutron fluence inside a central cavity with characteristic dimension r.

Under all conditions so far studied, the neutron spectrum shows a broad log-normal distribution peaking at just under 1 MeV. In a 2 m radius central cavity of a detector with coverage down to $|\eta| = 3$, the average neutron flux is 2×10^{12} cm^{-2}yr^{-1}, including secondary scattering contributions.

Values of A and α are given in Table 12.6 for several relevant situations. Examples of scaling to other accelerators are given in Table 12.7. It should be noted that the assumption that all radiation comes from the interaction point does not apply to the present generation of accelerators.

Table 12.6: Coefficients $A/(100\text{ cm})^2$ and α for the evaluation of calorimeter radiation levels at cascade maxima under SSC nominal operating conditions. At a distance r and angle θ from the interaction point the annual fluence or dose is $A/(r^2\sin^{2+\alpha}\theta)$.

Quantity	$A/(100\text{ cm})^2$	Units	$\langle p_\perp\rangle$	α
Neutron flux	1.5×10^{12}	cm^{-2}yr^{-1}	0.6 GeV/c	0.67
Dose rate from photons	124	Gy yr^{-1}	0.3 GeV/c	0.93
Dose rate from hadrons	29	Gy yr^{-1}	0.6 GeV/c	0.89

Table 12.7: A rough comparison of beam-collision induced radiation levels at the Tevatron, UNK, high-luminosity LHC, and SSC.

	Tevatron	UNK-3	LHC	SSC
$\sqrt{s}$ (TeV)	1.8	6	16	40
$\mathscr{L}_{\rm nom}$ (cm^{-2}s^{-1})	2×10^{30}	4×10^{32}	$4\times 10^{34\,a}$	1×10^{33}
$\sigma_{\rm inel}$	59 mb	80 mb	86 mb	100 mb
H	4.1	4.5	6.3	7.5
$\langle p_\perp\rangle$ (GeV/c)	0.46	0.52	0.55	0.60
Relative dose rate^b	5×10^{-4}	0.2	27	1

[a] High-luminosity option.
[b] Proportional to $\mathscr{L}_{\rm nom}\,\sigma_{\rm inel}\,H\,\langle p_\perp\rangle^{0.7}$

The constant A includes factors evaluated with cascade simulation programs as well as constants describing particle production at the interaction point. It is felt that each could introduce an error as large as a factor of two in the results.

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* *Dose* is the time integral of *dose rate*, and *fluence* is the time integral of *flux.*

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