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UCL/HEP 95-01

UNIVERSITY COLLEGE LONDON
DEPARTMENT OF PHYSICS
AND ASTRONOMY

Detectors and Backgrounds for a Muon-Muon Collider. Working Group Report

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Abstract. First estimates of background muon fluxes at a detector vary by more than two orders of magnitude. More realistic calculations are needed. If the lower rates apply then it should be possible to build an experiment with the acceptance and performance required to study the major topics in the physics programme. Some features of a possible solenoid detector have been investigated, with tracking and calorimetry covering angles to within ± 125 milliradians of the beam direction.

INTRODUCTION

This was a small group, but it had members from a range of current e^+e^-, ep and $p\bar{p}$ experiments - as well as veterans of the SSC detector design and simulation campaigns. For many of us it was a first look at the problems of building a detector for a muon collider and we were apprehensive about backgrounds. Willis' introductory talk (1) convinced us that the problems may be tractable, and we examined his assumptions in our discussions. The main verdict is that more detailed lattice and insertion designs are needed before backgrounds can be well enough understood to be sure that a detector can be built to do the important physics at a muon collider.

BACKGROUNDS

Primary backgrounds from muon decay are large and calculable. Decay electrons must be degraded rapidly by synchrotron radiation and absorbed in heavy shielding-collimators. Secondary interactions and beam-halo muons are much more problematical. Willis (1) has given estimates of $10^6/\text{m}^2$ per crossing at 10 cm radius, in a vertex tracker, and $10^4/\text{m}^2$ at 1m radius in a main tracker. The group agreed that suitably modular pixel detectors could work at such background levels. But are these levels realistic?

As a first step towards a serious prediction, Mokhov presented preliminary simulations of the secondary backgrounds from beam-halo muons interacting in a

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Reporting work done at the workshop *Physics potential and development of* $\mu^+\mu^-$ *colliders*, Sausolito, California, November 17-19 1994.

specimen detector-insertion. The parameters of the insertion are shown in Table I. The low-beta combined-function quadrupole QF2 is the vital element. It penetrates deep inside the detector to within ±1.2 m of the collision point - giving a β^* of 3 mm. It has a tapered bore, from 45 mm radius at 12.8 m from collision down to 4.5 mm at 1.2 m. Its superimposed bending field degrades decay electrons by synchrotron radiation and sweeps them out into the heavy metal lining of the bore. The other insertion magnets are all superconducting, but this closest one to the detector has a normal coil to cope with the large energy-deposition from showering.

Table I. Parameters of 2x2 TeV Collider Insertion Triplet.

Used in Mokhov's Monte Carlo calculation of backgrounds falling on a detector. All three quadrupole elements (QF, QD) combine focusing and bending. All magnets except the final quadrupole (QF2) are superconducting (SC).

Element	**Length, metres**	**R_{in}, cm**	**R_{out}, cm**	**$B_{max.}$, Tesla**	**Grad, Tesla/m**	**$B_{deflect}$, Tesla**
Pipe	1.2					
Iron QF2	11.6	0.45-4.5	35	1.5	3.33-0.33	0.5
Pipe	0.5	8.0				
SC B3	3.0	8.0	35			8.0
Pipe	0.5	8.0				
SC QD1	12.0	8.0	35	-4.0	-0.5	2.0
Pipe	0.5	8.0				
SC B2	3.0	8.0	35			8.0
Pipe	0.5	8.0				
SC QF1	6.2	7.5	35	4.0	0.533	2.0
Pipe	0.5	8.0				
SC B1	30.0	8.0	35			8.0

The most serious contribution to the background in these first simulation runs comes from muons in the beam halo interacting at a 3σ aperture in QF1 35 metres from the beam-crossing point. They produce electron positron pairs, bremsstrahlung and showers which build up in the magnet materials as they approach the detector region. The dangerous part of the background at the detector comes from tertiary muons which cannot be absorbed by any feasible amount of absorber. This initial result predicts background rates which are 600 times bigger than those estimated by Willis.

The group agreed with Mokhov that there were clear improvements which could be made to his first trial scenario. Apertures in the final insertion should all be at more than 5σ, and the beam halo should be controlled by scrapers in the arcs of the machine, far away from experiments, with toroidal sweepers to get rid of the scraped-off muons.

Soft showers from electron interactions in the tapered bore of the last quadrupole can be shielded from the experiment by the addition of a solid heavy metal "nose" reaching in from the end of the quadrupole to within 15 cm. of the collision point (figures 1 and 3). The inner bore of the nose would match that of the quadrupole, but would flare out gently as it approached the collision point so that most of the shower products from the narrowest beam opening at the opposite side would bury themselves inside the hole rather than hitting the front of the nose and backscattering. As drawn, the nose would present up to 1.05 m of material to showers coming out of the quadrupole yoke; over 240 radiation lengths if it is made of tungsten. Its outer surface may benefit from a thin layer of aluminium to help contain showers due to particles coming from the detector side.

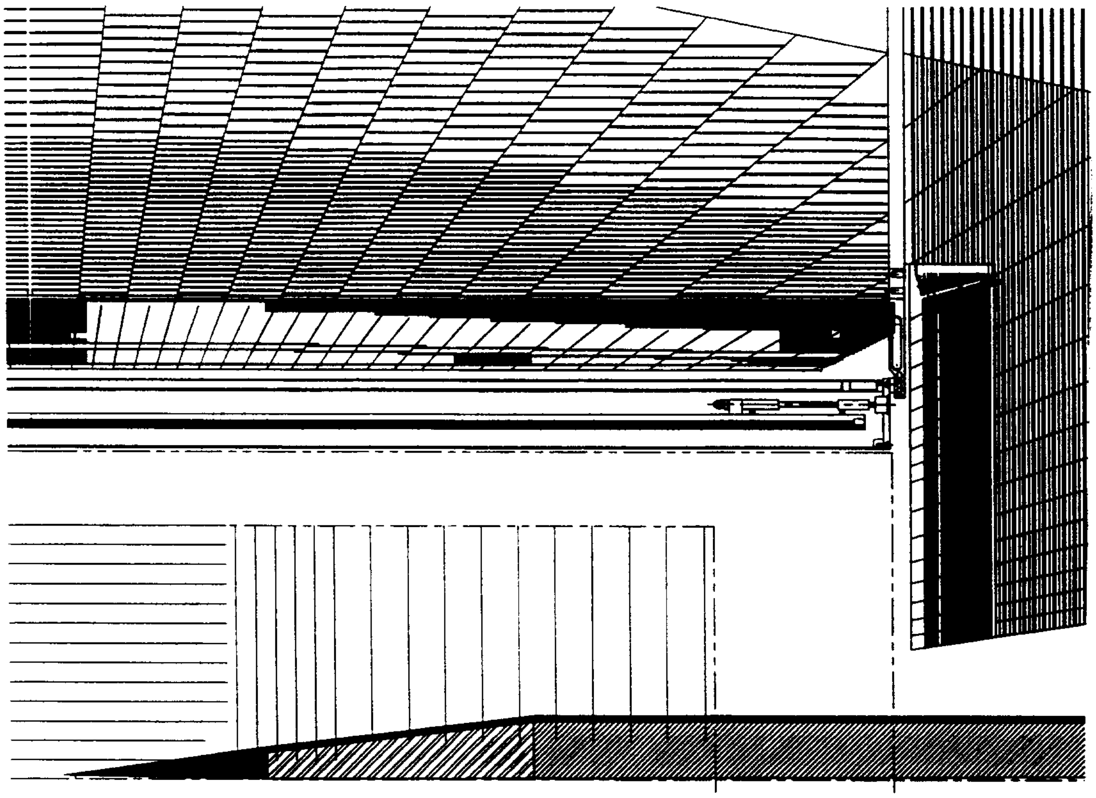

Figure 1. Quadrant-section of a generic detector; (based on the SDC design for SSC, unoptimised) with Mokhov's innermost quadrupole (QF2, Table I) inserted. The tungsten shielding "nose" is heavily shaded. The tapered part of QF2 may be a permanent magnet, with a conventional iron electromagnet for the parallel part. The dark layer around the quadrupole is the "bucking coil", see Figure 2 and text. Tracking is shown to within 125 milliradians of the beam direction.

Two very thorough exercises are needed before a reliable estimate of backgrounds can be made. Mokhov's insertion region design can only be of limited use if it is not matched to a whole machine, so a complete collider lattice design must be put together. Halo muons and scraped muons can then be tracked from wherever they leave the beam envelope. And EGS Monte Carlo simulations have to be made to see how effective such shielding devices as the tungsten nose can be - and the electron-absorbers in the magnet bores. Stumer is setting up EGS to do this.

DETECTOR FIELD CONFIGURATION

Three possibilities were discussed and two of them were soon dismissed. There was no enthusiasm for a toroidal layout. A dipole, or split field dipole, could have minor advantages in keeping the detector field clear of the final combined function quadrupole, but there are at least two serious disadvantages. Dipoles have bad-field directions in which outgoing tracks are not bent, and they can give transverse fields at the interaction point. Such a transverse field would be a double disaster, bending soft electron tracks into the trackers in the horizontal plane with such intensity that they would generate even softer delta rays and other secondaries which spiral along a field lines - filling the whole volume of the detector up with background hits.

A solenoid was seen as the most attractive option, with good acceptance for the high p_T tracks from high mass-scale physics, but capable of trapping low p_T background tracks close to the beam and leading them into the shielding nose. There was concern that the solenoid field would saturate the yoke of Mokhov's normally-conducting final magnet, causing field distortions, but Foster's *Poisson* calculation showed that a suitable configuration of normally-conducting bucking coils could be found to screen the solenoid field out from the combined-function magnet. Figure 2 is a cross-section through a suggested combination of conical and cylindrical bucking coils, showing how the solenoid field-lines could be made to run along the beam direction into the region of the tungsten shielding nose, taking away soft charged-particle backgrounds. The lines are pushed away from the beam axis further from the interaction point. There may be scope for the last metre or so of the magnet to be a permanent quadrupole - if only to ease the space problems of getting current in to the forward cone.

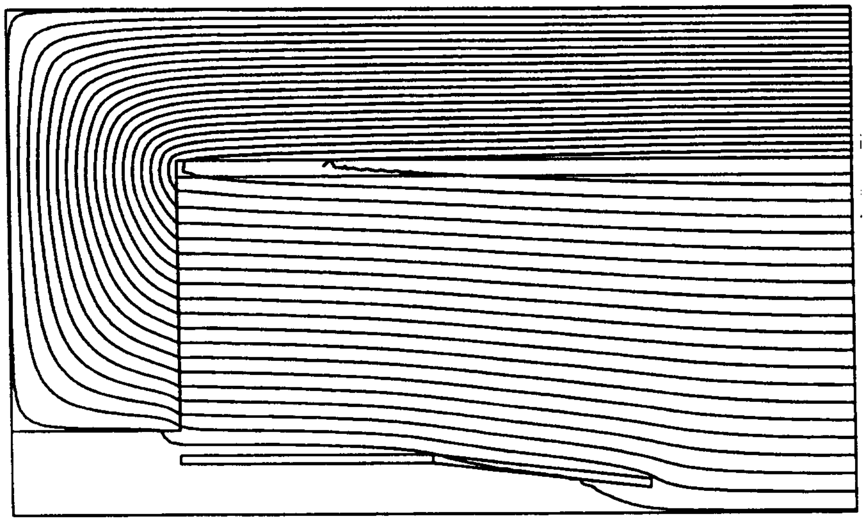

Figure 2. Poisson(2) calculation of solenoid field with bucking coils.
The coil and the conventional iron yoke and pole-pieces of the solenoid can be seen in this single- quadrant section. Conical and cylindrical coils around the beam have been tuned to give a finite field at the interaction point, in order to contain soft background tracks, while eliminating fields in the region of the QF2 quadrupole.

DETECTOR REQUIREMENTS

The main goals are:

- Beauty tagging;
- Sign of charge for full energy e and μ;
- e and μ identification, but not K, π, p;
- Missing Transverse Energy measurement;
- Background toleration.

The group had no disagreements with the Willis approach (1) - so long as the backgrounds are as low as he assumes.

LEP and SLD show that for beauty tagging it will be very important for the innermost layers of silicon pixels to be within a few centimetres of the beam axis. Figure 3 shows how they might be fitted around the tungsten shielding nose. CCD detectors might be able to do this job if they have a common-clear mode which can run continually between untriggered beam-crossings - giving a complete clear within 5 or so crossings. For heavier background rates than Willis assumed, faster-clearing smart pixels would be needed.

Measuring lepton charges needs good resolution over the whole of the main tracker. Willis suggest a multiwire chamber system with pixel-pads to give good background rejection. Assume the pad-readout gives ±50 microns precision in r-φ, with a 1.5 T solenoid field over a tracker with outer radius 1.8 metres. This would give momentum resolution of ±2% for a track with 100 GeV transverse momentum, or ±40% at 2 TeV - just about enough to resolve the sign of the charge.

Electron identification requires good energy resolution in the electromagnetic calorimetry layers so that the deposited energy can be matched with momentum from the tracker. For muon identification Willis' low density calorimetry would be especially attractive if the hadron absorber could be magnetised to give ~3% momentum resolution on muons picked up by an outer tracker.

Muon identification close to the forward and backward directions would be helped by toroidal magnets upstream and downstream of the main detector. Depending on the background fluxes, such toroids might even pick up high energy muons which have been produced within the ±125 milliradian cone of Figures m and o, and passed through the tungsten nose and the first part of the insertion magnet.

Missing transverse energy measurement will depend upon good hadron calorimetry, with hermetic coverage down to the ±125 milliradian cone.

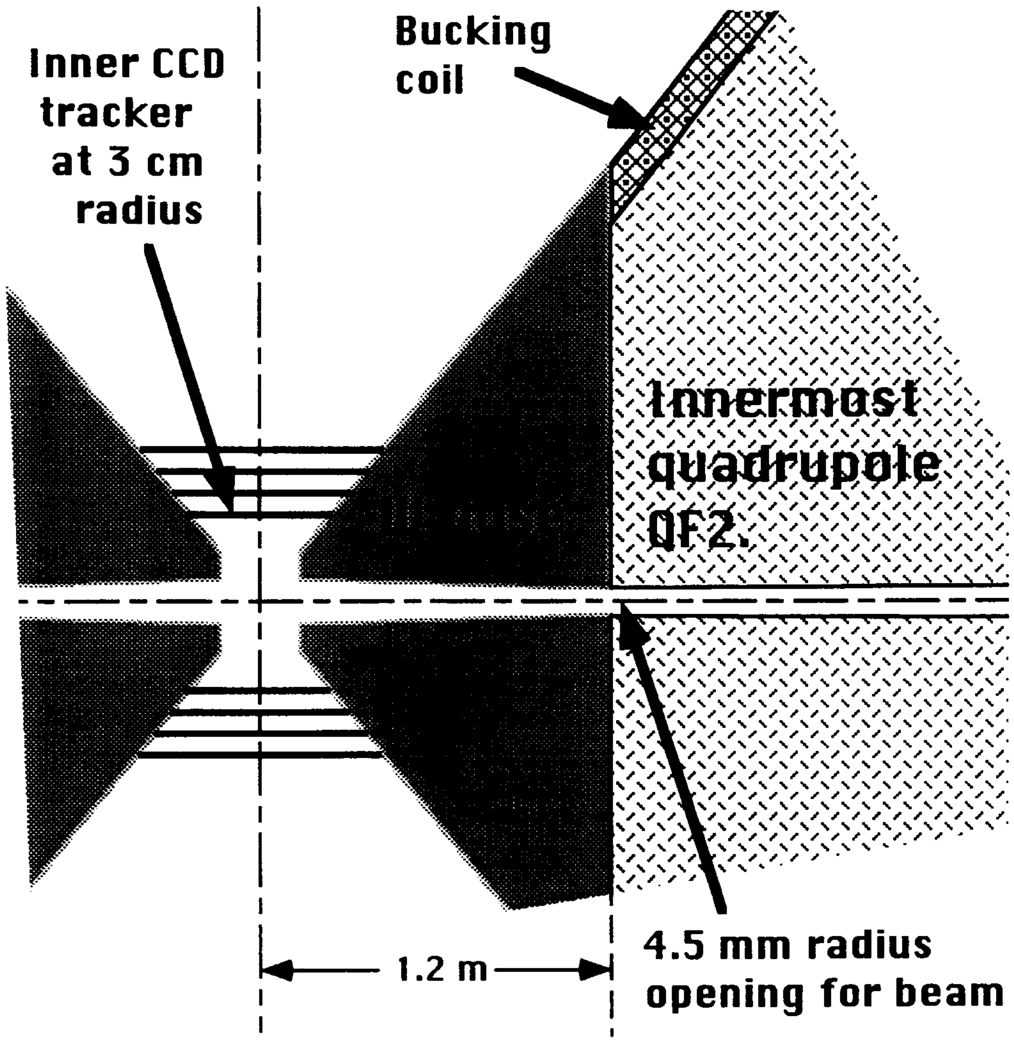

Figure 3. Vertically magnified view of the intersection region.
The vertical scale is 10x the horizontal, for a similar layout to Figure 1. The tungsten shielding nose is shown opening up in aperture from the narrowest opening where the beam leaves the QF2 Quadrupole. A tracker in the position shown will be well shielded from soft electromagnetic background.

LUMINOSITY MONITORING

Because of the small momentum-bite of a circular muon collider, and the low beamsstrahlung, there is no need to monitor the luminosity spectrum in the same way as at an electron-positron linear collider. But the calculations done for Bhabha scattering at the linear collider (3) can be taken over for $\mu\mu$ elastic scattering. The basic pointlike electromagnetic annihilation (s-channel) cross-section at a muon collider sets the unit of R

$$\sigma^{\gamma}_{\mu\mu\to ee} = \sigma^{\gamma}_{ee\to\mu\mu} = \frac{87 fb}{s(TeV^2)}$$

Other cross sections are measured with respect to this, e.g.

$\sigma_{t\bar{t}} \rightarrow \approx 0.75R$ away from threshold,
$\sigma_{WW} \approx 12R$, depending on acceptance,
$\sigma_{\gamma\gamma} = 2R$, for two real γ.

Elastic $\mu\mu$ scattering has an additional contribution from t-channel γ-exchange, and interference between the s- and t-channels gives significant enhancement even in the barrel region, see Table II.

Table II. Elastic $\mu\mu$ scattering.
(Bhabha scattering rates taken over from (3)).

Angle to beam direction	**Rate**
180-300 mr.	223R
300-800 mr.	104R
800- 2341 mr.	8R

A few interesting cross sections rise like log s (for instance $\mu\nu W$ or $\mu\mu Z$ which plateau at ~10 pb; i.e. ~100R for $\sqrt{s} = 1TeV$), but possible Higgs rates are never much more than R.

We conclude that we can monitor the luminosity with sufficient precision for all likely physics channels so long as we can measure the $\mu\mu$ elastic scattering rate for $\theta > 300$ mr. The detector needs to be able to identify collinear muon pairs at beam energy. If it can not do that, what can it do?

VERDICT

A suitable detector can be built; if the background can be brought down to the level Willis assumes (1). Three things are needed to demonstrate that these levels can be achieved:

- a full lattice calculation for the collider;
- EGS simulations of showering, all the way from beam losses in the collider, through collimators, magnets and shielding to the detector;
- agreement between groups checking each other's results.

FNAL is tackling the lattice problem and BNL is running EGS. There is a good chance that firm background predictions will be available for a workshop in November 1995. That will be the time to start on serious detector design.

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1. Willis, W. *Overview of Detectors*, these proceedings.
2. *Users guide to the Poisson/Superfish group of codes*. Los Alamos report LA UR 87 115.
3. Frary, M.N. and Miller, D.J. *Monitoring the Luminosity Spectrum*; in *e^+e^- Collisions at 500 GeV, The Physics Potential*, ed. P.M. Zerwas (1992) DESY 92-123.