Muon background reduction in CLIC

Introduction

- Muons created in the beam delivery system, especially in the collimators, can cause backgrounds in the detector.
- The predicted muon flux, and feedback from the detector group regarding its impact on the detector, is presented.
- A method of reducing this flux using magnetised toroids and detailed tracking studies are presented along with suggestions and plans for future work.

Halo generation

- The tracking was done in two stages: firstly, a halo distribution was generated by H. Burkhardt using HTGEN-PLACET. This was then tracked from the first vertical betatron spoiler to the detector using BDSIM/GEANT4, including muon production processes.
- Firstly I will present the latest slides by H. Burkhardt which describes how the halo was calculated...
- I will then discuss the BDSIM simulation.

Muon background update (1/2)

tails in the beams, collimation, etc

by Helmut Burkhardt

Halo sources

Particle processes : beam gas, elastic and inelastic (Bremsstrahlung), thermal photon - estimates exist.

Optics related : mismatch, coupling, dispersion, non-linearities -- would require tracking with realistic machine, tracking so far was with ideal machine

Various : noise and vibrations, dark currents, wakefields -- not simulated for halo

By experience :

the actual amount of beam halo is very hard to predict and may vary considerably in a given machine.

Beam gas elastic scattering

total cross section

$$\sigma_{\rm el} = \frac{4\pi\, Z^2\, r_e^2}{\gamma^2\, \theta_{\rm min}^2}$$

at constant normalized emittance

$$\epsilon_N = \gamma\, \epsilon$$

scaling as 1/γ or 1/energy
beginning of LINAC important

$$\sigma_{\rm el} = \frac{4\pi\, Z^2 r_e^2\, \beta_y}{\epsilon_N\, \gamma}$$

CLIC 2007 estimate. P = probability / m for scattering > 1 σ divergence

Location	E GeV	Gas	ρ m^{-3}	$\sigma_{\rm el}$ Barn	P m^{-1}
LINAC	9	CO	3.2×10^{14}	2.7×10^{7}	8.9×10^{-7}
BDS	1500	CO	3.2×10^{14}	1.7×10^{5}	1.1×10^{-8}

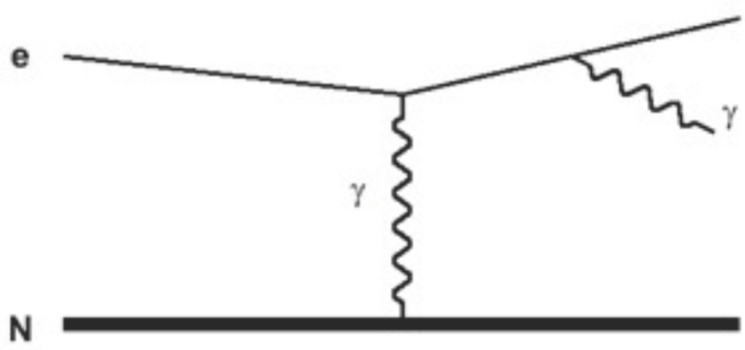
Probability 80x higher beginning of LINAC at 9 GeV compared to end at 1.5 TeV and BDS. Integrated over length :

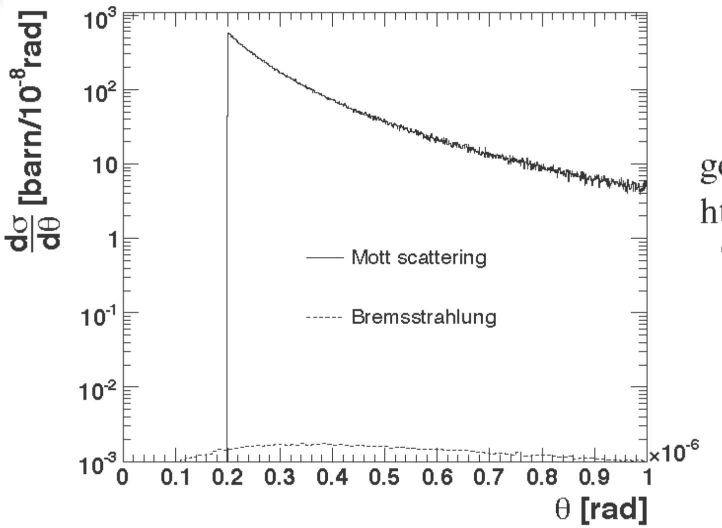
total LINAC Prob. P = 1.16×10^{-3} , BDS P = 6.0×10^{-5} together 1.2×10^{-3} at 1σ

total LINAC Prob. P = 1.29×10^{-6} , BDS P = 6.7×10^{-8} together 1.4×10^{-6} at 30 σ (loss)

placet-htgen simulation LINAC+CLIC fraction of 2×10^{-4} lost at spoilers (2007 estimate, 10nTorr)

Inelastic scattering





generated with htgen example TestProcess

scattering angle (of γ with respect to incident e) $f(\theta)d\theta \propto \frac{\theta\ d\theta}{(\theta^2+\gamma^{-2})^2}$.

energy fraction k going to photon $\frac{d\sigma}{dk} = \frac{A}{N_A X_0}\frac{1}{k}\left(\frac{4}{3} - \frac{4}{3}k + k^2\right)$

integrated for k > 1%, no E dependence
σ = 6.609 Barn for N_2

$$\sigma_{\text{in}} = \frac{A}{N_A X_0}\left(-\frac{4}{3}\log k_{\text{min}} - \frac{5}{6} + \frac{4}{3}k_{\text{min}} - \frac{k_{\text{min}}^2}{2}\right)$$

Probability: 2.1×10^{-13}/m
summing up over both LINAC and BDS : $P = 5.0\times10^{-9}$

fully included in current HTGEN, minor contribution for CLIC

2011 update, 1nTorr

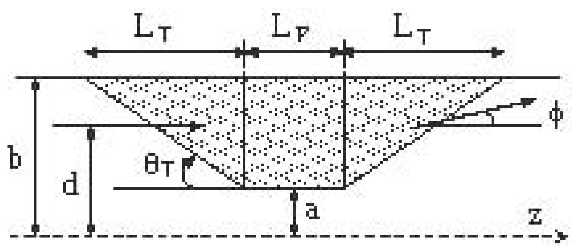
2007 estimate, 10 nTorr
total LINAC Prob. $P = 1.16 \times 10^{-3}$, BDS $P = 6.0 \times 10^{-5}$ together **1.2×10^{-3} at 1σ**

2011 estimate, 1 nTorr and larger emittance
total LINAC Prob. $P = 8.69 \times 10^{-5}$, BDS $P = 4.5 \times 10^{-6}$ together **9.1×10^{-5} at 1σ** ($13 \times$ less)

if same fraction lost at spoilers : would now expect ~ **1.5×10^{-5}** of electrons lost at spoilers

requires new improve simulations, see last slide

Table 2: Geometry of the BDS spoilers and absorbers. The radiation lengths for Be and Ti are X_0=0.353 m and X_0=0.036 m, respectively.



Name	a_x [mm]	a_y [mm]	θ_T [mrad]	L_F [X_0]	L_T [mm]	Mat.
ESP	3.51	8	50	0.05	90	Be
EAB	5.41	8	100	18	27	Ti
the following ×4						
YSP	8	0.1	88	0.2	90	Ti
XSP	0.12	8	88	0.2	90	Ti
XAB	1	1	250	18	27	Ti
YAB	1	1	250	18	27	Ti

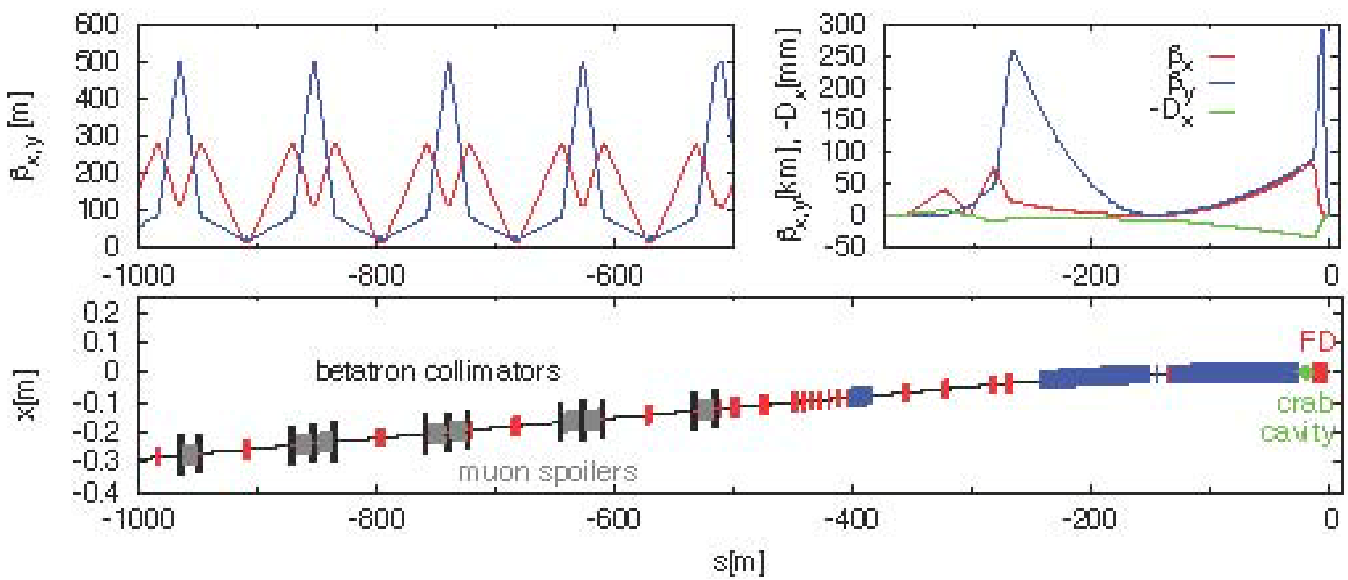


Fig. 3: Optics (top) and layout (bottom) of the CLIC betatron collimation and final focus sections.

Ongoing work - updated and improved halo simulation

Requires a new set of **placet-htgen** simulations of the combined **LINAC+BDS** system

Work on code and LINAC + BDS input files (.tcl)

Work on code ongoing, with help of Andrea Latina et al. on the placet part

Main steps and goals :

- **localize and remove any segmentation faults**
- **improved makefiles placet with htgen**
- **improved diagnostics (export HTGEN_DEBUG=16 ...)**
- **more flexibility in generation of output (selection of elements for track output)**
- **(semi-) automatic normalization**
- **create sample / test jobs relevant for CLIC halo and verify regularly**

BDSIM Simulation

- The beam delivery system was simulated using BDSIM (a Gean4 tool kit for the simulation of beam lines including the passage of particles through matter).
- The lattice was derived from the MAD deck (Rogelio Tomas).
- The input e- halo distribution and normalisation factors were generated using htgen-placet – as described in the previous slides.
- Without any muon spoilers the flux at the detector was predicted as ~200 muons per bunch per beam.

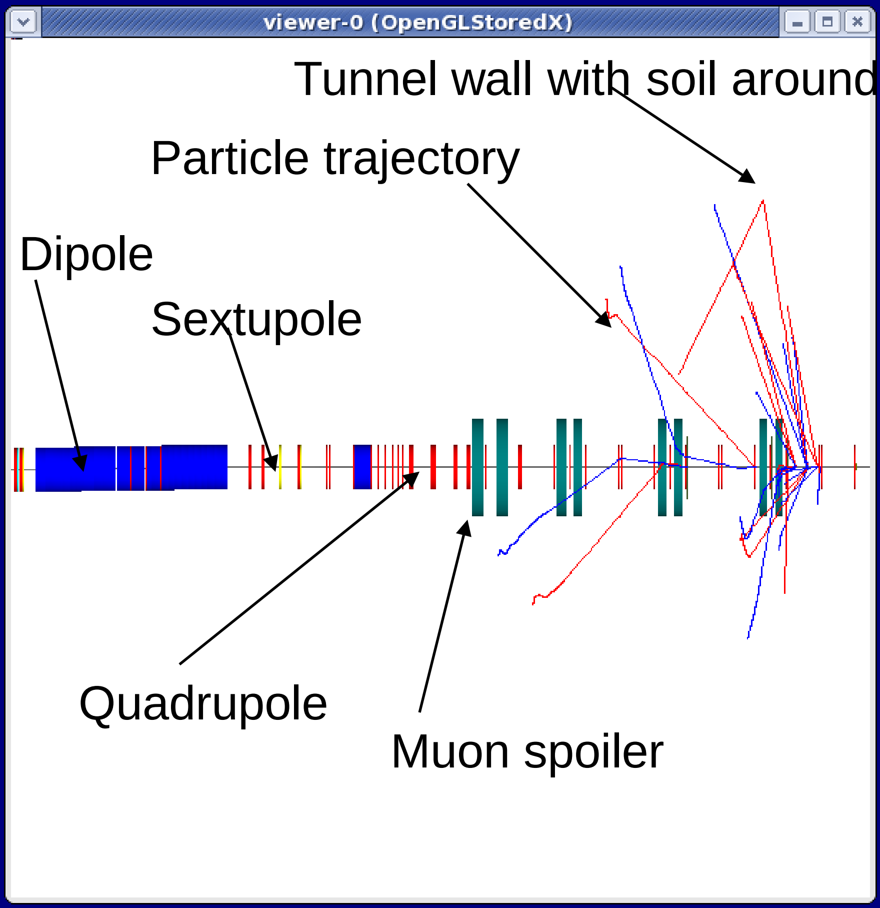
BDSIM Simulation

- As well as the usual electromagnetic proccesses (bremsstrahlung, annihation, gamma to e+ e- pair), the following cross section enhanced muon production processes are simulated:
- $\gamma \longrightarrow \mu^+ \mu^-$
- $e^+ e^- \longrightarrow \mu^+ \mu^-$

Impact on detector

- Detector CDR: “In summary, at the level of one muon per BX, the beam halo muon background does not constitute an unsurmountable problem for the detector concepts being considered here, i.e., in detectors which have sufficient granularity and timing resolution in the calorimeters.”
- Therefore, the muon flux would need to be reduced.
- Reducing linac pressure from 10n Torr to 1n Torr gives a factor 13 improvement.
- Further reduction needed -> toroidal fields.

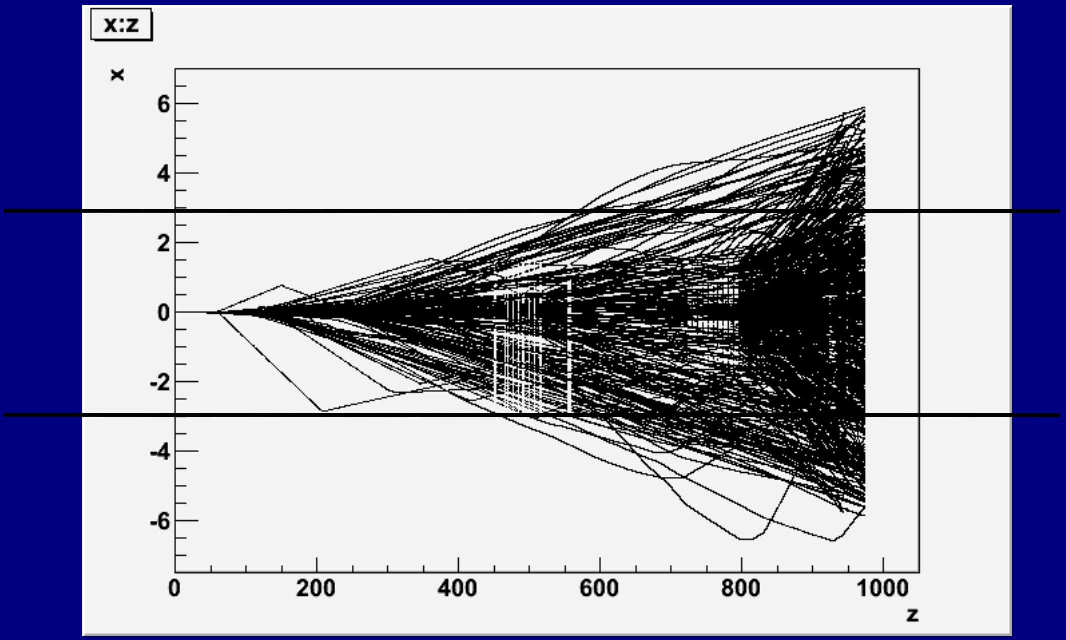
Geometry



- Left: screen shot, 1 event, beam travels right to left
- Tunnel included
- Muon spoilers 55cm outer radius, 1cm inner radius, 1.5T solenoid field, ~100m downstream of collimators. Total length ~80m.

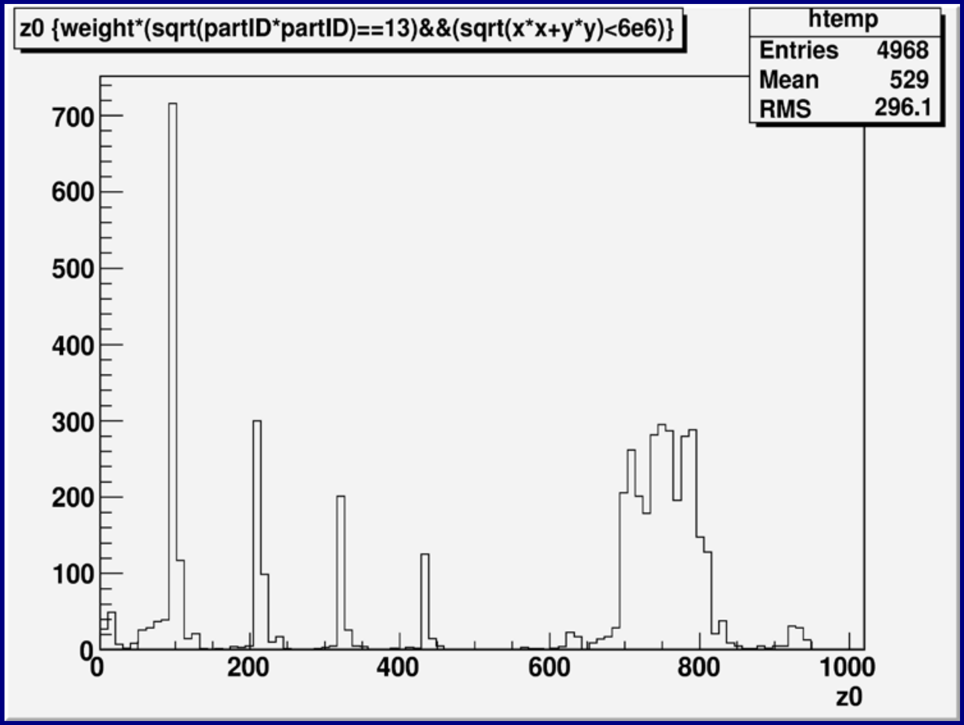
Flux to detector

- The muon flux to the detector (within r=6m) is reduced by factor 10 compared to no muon spoilers
- Right: sample of tracks of remaining muons, x [m] vs z [m]
- The horizontal lines show where the walls of the tunnel are

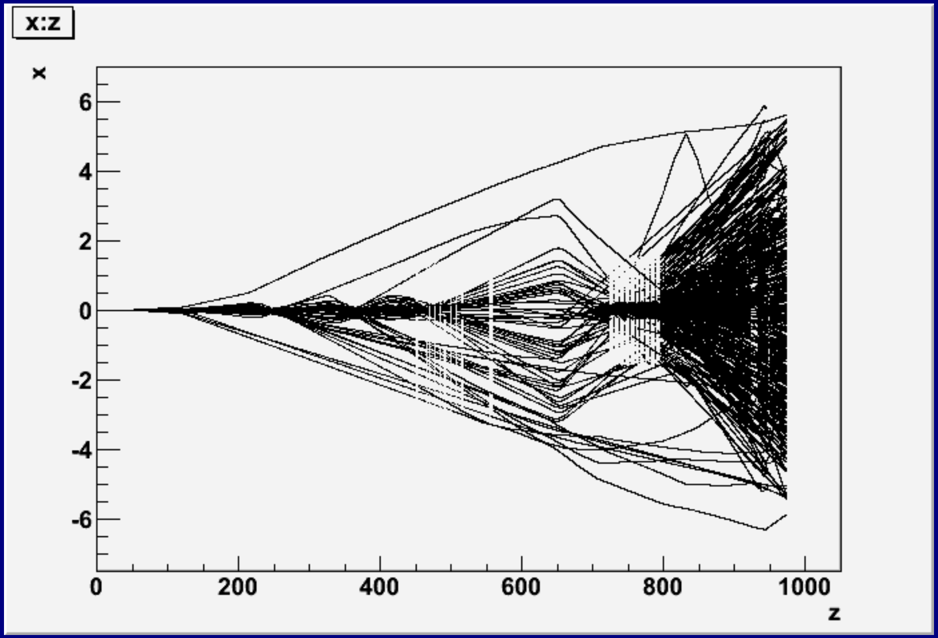


Origin of muons

- To further reduce the flux, wanted to find out where the remaining muons were coming from
- Histogram of the Z position were a muon reaching the detector was created was plotted.
- 4 peaks seen
- Long section corresponding to long dipole ~600m to ~800m



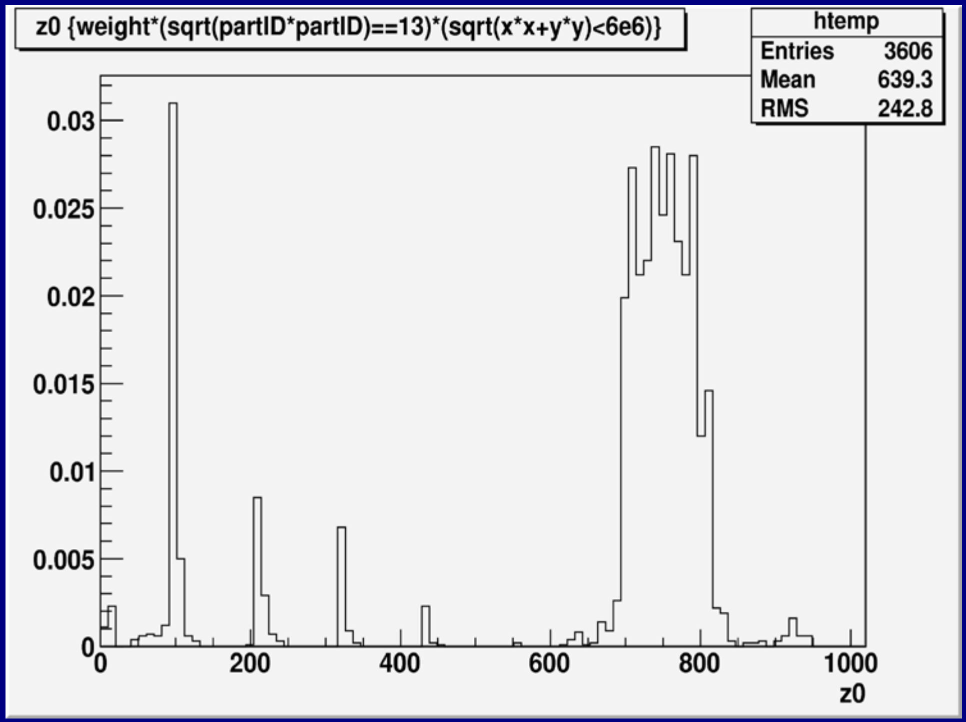
Addition of tunnel filler



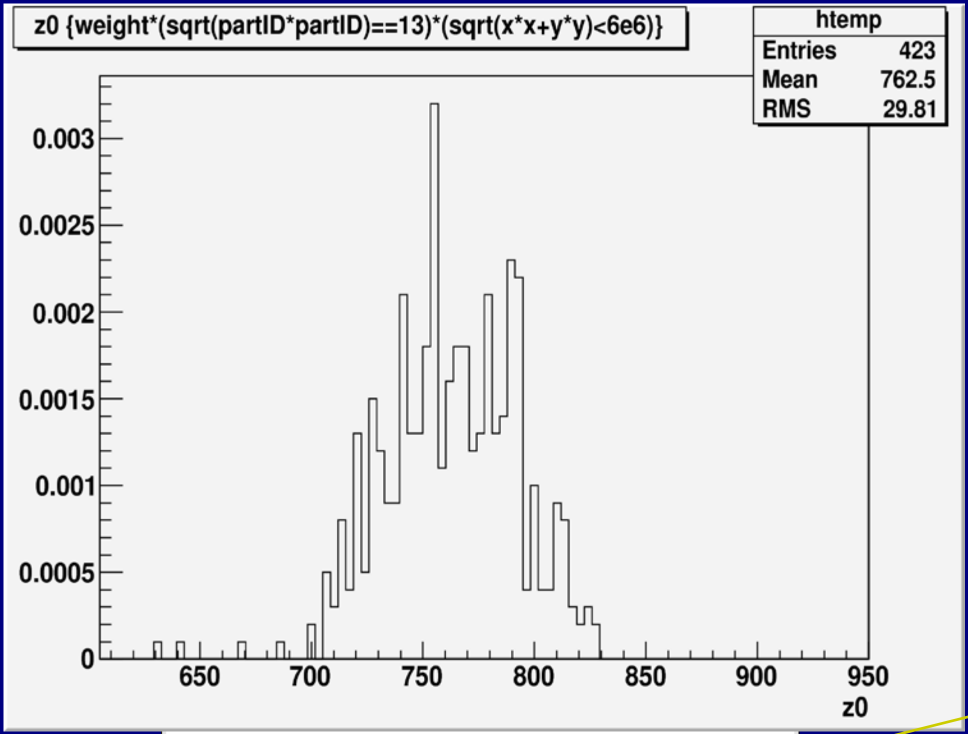
- The results suggested that adition of magnetised tunnel filler at around ~625m form YSP1 could help
- The muon flux to the detector (within r=6m) is reduced by an additional factor of only 1.5 with the tunnel filler

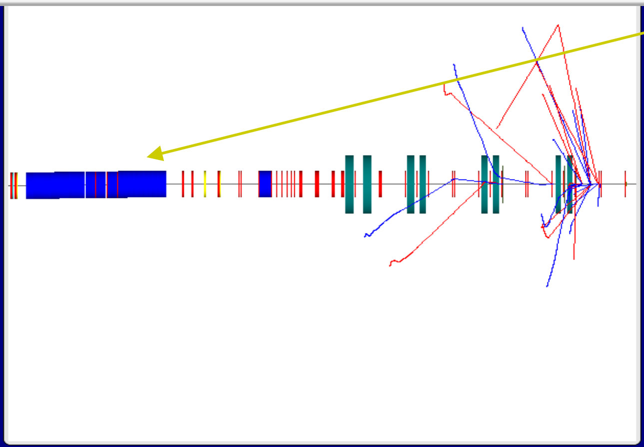
Addition of tunnel filler

- Most of the remaining muons seemed to be generated in the long dipole downstream of ~600m



Remaining muons

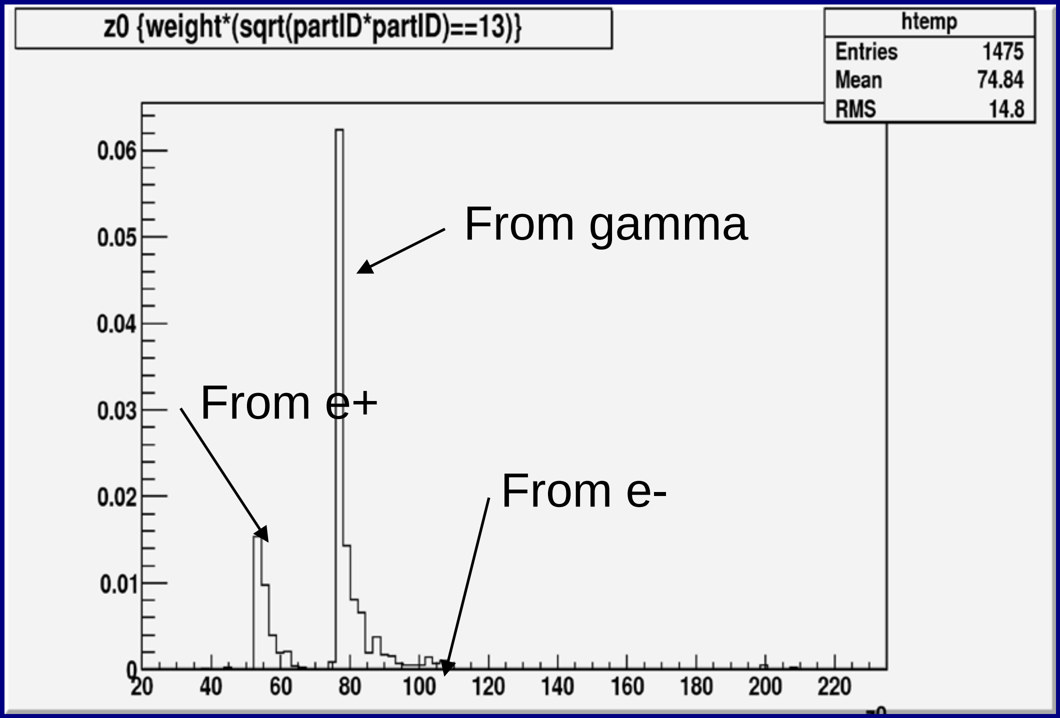




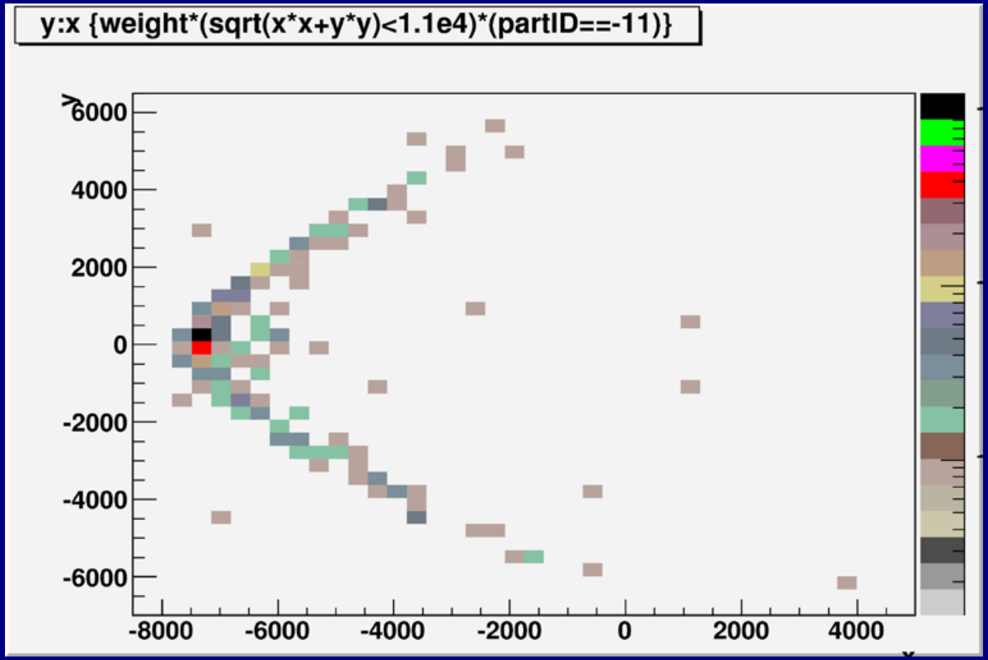
- If all drift spaces are filled with magnetized tunnel fillers – 3.5m outer radius – then this gives a similar muon flux to having just muons spoilers plus tunnel filler – so adding more magnetised iron would probably not help.
- The remaining muons are created in the long dipole section (mffb3 onwards).
- 90% of the remaining muons are created in these dipoles

Remaining muons

- Particles inside the beam pipe were tracked from the start of the final focus dipole BFF3.
- Right: origin of muons hitting the detector – number of particles (not normalised) vs. distance from start of BFF3 (metres).

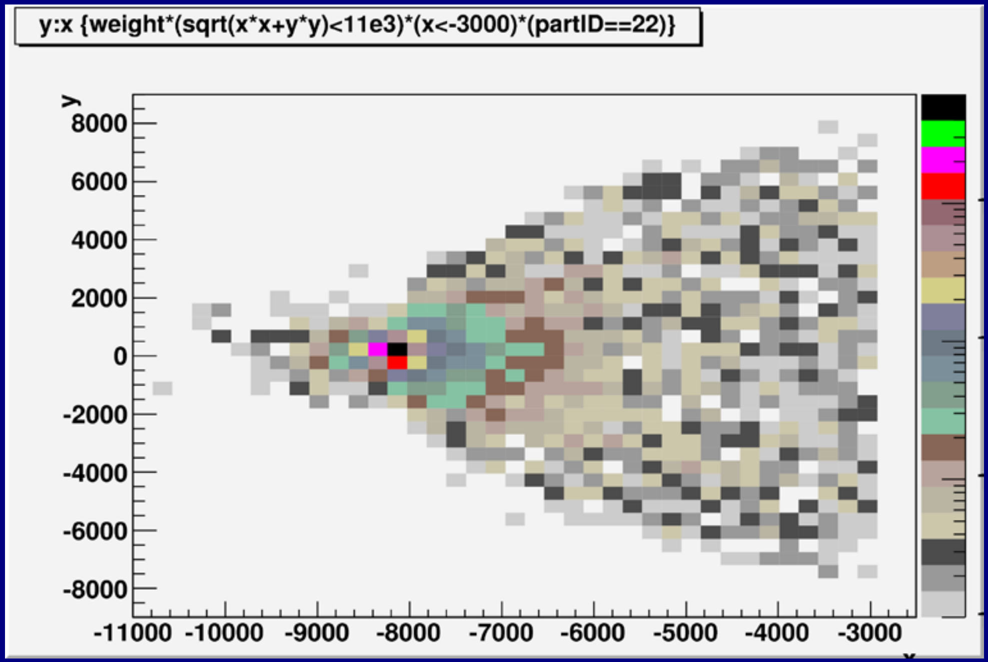


e+ hitting beampipe



- Distribution – x[mum] vs. y[mum] – near the z location where the e+ hit the beam pipe wall (8mm beam pipe radius)
- 20% of the muons created in the FF dipoles are from these e+

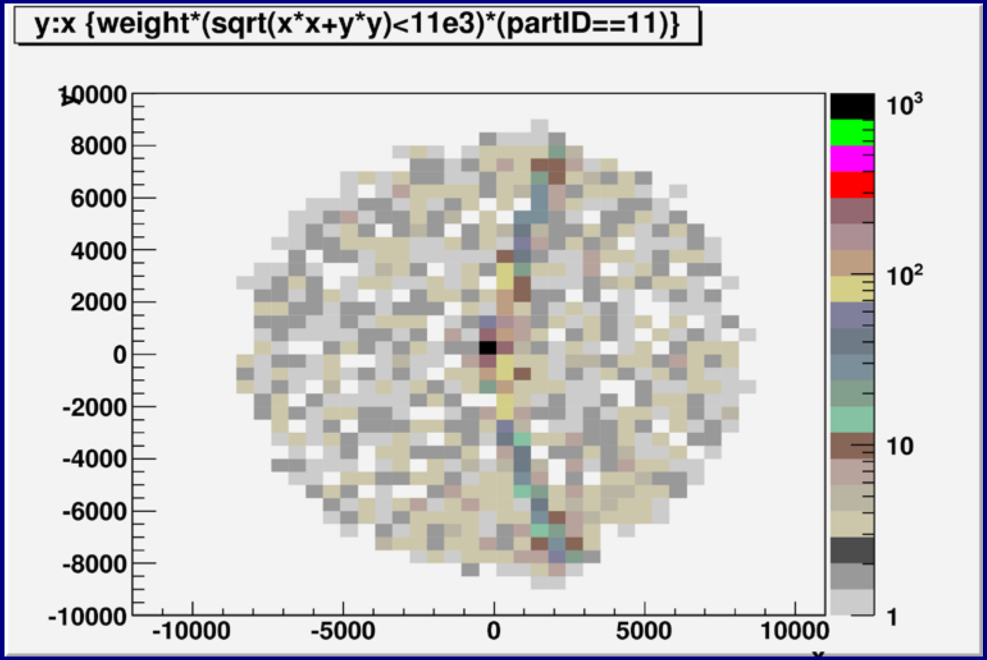
Photons hitting beampipe



- Same plot for photons (different z location)
- 75% of the muons created in the FF dipoles are from these photons

e- hitting beam pipe

- The electrons hit near the y-axis of the beam pipe as they have a vertical momentum.
- ~5% of the muons created in the FF dipoles are from these electrons



Extracts from CLIC detector CDR

"High energy secondary muons are produced in inelastic collisions in the collimation of the beam halo particles and may reach the experimental cavern and the detector. This beam halo muon background can be reduced significantly through adaptations of the collimation scheme and through the placement of passive and/or magnetised iron spoilers in the BDS. Detailed tracking studies of the muons through the BDS have been performed. Preliminary results indicate that it is realistic to aim for an average of one muon per bunch crossing (combined from both beams) traversing the detector volume. Further information is given in the CLIC CDR Volume 1, Section 2.5.3. For this report, one muon per BX is therefore assumed…

…In summary, at the level of one muon per BX, the beam halo muon background does not constitute an unsurmountable problem for the detector concepts being considered here, i.e., in detectors which have sufficient granularity and timing resolution in the calorimeters. Further studies are needed on reducing the number of halo muons reaching the detector, as well as on mitigating their impact using more sophisticated pattern recognition algorithms."

Extracts from CLIC detector CDR

"High energy secondary muons are produced in inelastic collisions in the collimation of the beam halo particles and may reach the experimental cavern and the detector. This beam halo muon background can be reduced significantly through adaptations of the collimation scheme and through the placement of passive and/or magnetised iron spoilers in the BDS. Detailed tracking studies of the muons through the BDS have been performed. Preliminary results indicate that it is realistic to aim for an average of one muon per bunch crossing (combined from both beams) traversing the detector volume. Further information is given in the CLIC CDR Volume 1, Section 2.5.3. For this report, one muon per BX is therefore assumed…

…In summary, at the level of one muon per BX, the beam halo muon background does not constitute an unsurmountable problem for the detector concepts being considered here, i.e., in detectors which have sufficient granularity and timing resolution in the calorimeters. Further studies are needed on reducing the number of halo muons reaching the detector, as well as on mitigating their impact using more sophisticated pattern recognition algorithms."

Summary

- Work is ongoing to provide a new set of htgen-placet simulations of the linac-bds system. These will provide better estimates of the halo which is the input to the BDSIM simulation.
- There is a predicted factor 13 reduction in the halo after reducing the beam pipe gas pressure in the linac from 10 nTorr to 1 nTorr.
- Factor 15 fewer muons with spoilers + tunnel filler
- Factor 10 fewer muons with muon spoilers only
- With the muon spoilers and the linac pressure reduction combined the muon flux is reduced to 1.5 per beam per bunch crossing.
- Most of the remaining muons are created in the final focus section dipoles from secondary positrons and gammas – improve collimation system?
- With further improvements muon flux of 1 per BX, required in detector CDR, seems feasible. Improvements to detector algorithms are also envisaged. For full details see the detector CDR.

Energy spectrum of muons at detector

- Energy of muons at detector – (not normalised)