Feasibility of the re-development of the EMEC

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The EMEC

- ElectroMagnetic EndCap calorimeter

Simulation of the EMEC

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Feasibility study & next steps

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EMEC - ElectroMagnetic EndCap calorimeter

- The EMEC is a lead, liquid argon sampling calorimeter.
- Inner and outer wheel structure, covering $1.5 < \eta < 3.2$.
- Absorbers and electrodes form a wave/accordion structure.
- Amplitude of absorber waves increases with radius. The wavelength is constant.
- Leads to a twisting of the absorbers.

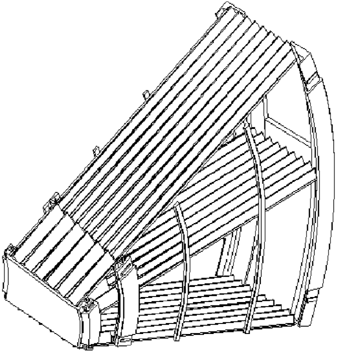

Figure: Structure of the EMEC wheels [1]

Present simulation of the EMEC

- When the present EMEC geometry was written, no suitable shapes existed within Geant4 to represent the absorbers.
- This required the definition of a custom solid geometry.
- This custom geometry is constructed based on calculations of the distance to a “neutral fibre” which defines the absorber/electrode shape.
- Custom solids are required to contain some methods for use by the navigation including DistanceToIn(), and DistanceToOut().

Motivation for re-development

- Detailed tests of the simulation performance [2] show that calls to the DistanceToIn(), and DistanceToOut() methods for the EMEC alone account for ~15% of the simulation time.
- All calls to the same methods for all other solids account for less than 2%.
- It was estimated that up to 10% of this CPU time could be recovered by re-developing the geometry.

Proposal for re-development

- A Geant3 description of the EMEC geometry existed, using twisted trapezoid solids to represent the absorber shape.
- The recent introduction of a twisted trapezoid solid into Geant4 has allowed this type to geometry to be re-implemented.

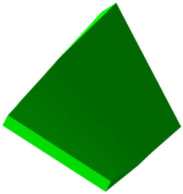

Figure: Example of the Geant4 twisted trapezoid solid

Proposal for re-development

- This twisted trapezoid solid has been used to implement a new Geant4 description of the EMEC.
- A feasibility test is underway to determine a representative estimate of how much, if any, CPU time can be recovered using this method.
- A decision on a full scale re-development can then be made based on these results.

Creating the new geometry

- A representative description of the EMEC was created using only Geant4 solids.
- Layers of electrode/absorber are constructed with 8 radial sections of twisted trapezoid, whose dimensions vary as a function of radius.
- Non-twisted trapezoids are also used, along with Tube and Cone solids.
- The inner wheel contains 6 absorber waves, with 9 in the outer wheel.

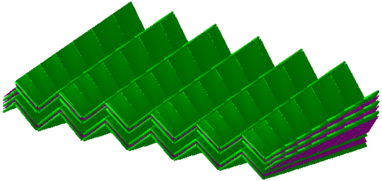

Figure: The EMEC Absorbers and Electrodes

Creating the new geometry

- The existing MORTRAN (a FORTRAN extension) description of the geometry used in Geant3 was used as a baseline.
- A Geant4 description (C++) was then written using this baseline.
- Some additional modifications were necessary in order to ensure compatibility with Geant4 and CLHEP.
- The result is essentially a Geant4 description of the geometry used to simulate the EMEC in Geant3.

Creating the new geometry

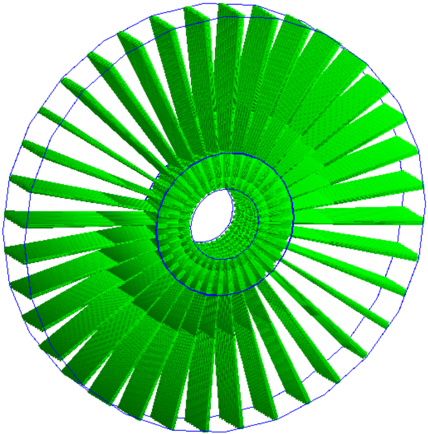

Figure: The EMEC Wheel

Results with twisted trapezoids

- The following slides show the results of comparison tests between the custom solid, and the new EMEC description.
- The tests use electrons of various energies.
- Tests divided into η regions to independently test the outer and inner wheel performance.
- Tests were conducted to find the optimal voxelization parameters.

Results with twisted trapezoids - inner wheel

- Inner wheel (using $2.8 < \eta < 3.0$)

Energy (GeV)	Custom solid (s)	New EMEC (s)	Difference (%)
2	1.3	4.7	+262%
20	13.4	39.5	+195%
200	134.2	318.7	+137%

Table: Comparison of CPU time requirements between the custom solid and the new twisted trapezoid representations in the inner wheel

Results with twisted trapezoids - inner wheel

- In the inner wheel:
- The agreement in the number of tracks is within 3%, at low energies and gradually reduces for higher energies.
- At low energies more steps are being simulated ($\sim$ 13% at 20 GeV), and at high energies less are being simulated.

Results with twisted trapezoids - outer wheel

- Outer wheel (using $1.9 < \eta < 2.1$)

Energy (GeV)	Custom solid (s)	New EMEC (s)	Difference (%)
2	1.5	4.2	+180%
20	11.9	28.6	+140%
200	158.5	274.3	+73%

Table: Comparison of CPU time requirements between the custom solid and the new twisted trapezoid representations in the outer wheel

Analysis of results

- To determine where the time is being consumed, some callgrind profiling was done.
- For a typical full detector simulation, $\sim$ 24% of the navigation time is taken by the method ComputeStep(), which calls the DistanceToIn() and DistanceToOut() methods.
- For the new EMEC simulation, $\sim$ 93% of the navigation time is taken by the method ComputeStep().
- $\sim$ 97% of this time is consumed in the DistanceToIn() and DistanceToOut() methods.
- $\sim$ 57% of the time spent in these methods is used to solve the high order polynomials describing the twisted surfaces.

Results with non-twisted trapezoids

- As a comparative performance test, all twisted trapezoids were replaced with non-twisted ones.
- The number of radial segments was increased by 50% to more closely model the absorbers in the absence of a twist.
- The same testing procedure was used.

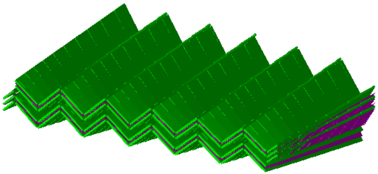

Figure: Increased number of radial sections with non-twisted trapezoids

Results with non-twisted trapezoids - inner wheel

- Inner wheel (using $2.8 < \eta < 3.0$)

Energy (GeV)	Custom solid (s)	New EMEC (s)	Difference (%)
2	1.3	1.44	+11%
20	13.35	13.58	+2%
200	134.2	120.1	-11%

Table: Comparison of CPU time requirements between the custom solid and the non-twisted trapezoid representations in the inner wheel

Results with non-twisted trapezoids - inner wheel

- In the inner wheel:
- The agreement in the number of tracks is within 3%, at low energies and gradually reduces for higher energies.
- At low energies more steps are being simulated ($\sim$ 10% at 20 GeV), and at high energies less are being simulated.

Results with non-twisted trapezoids - outer wheel

- Outer wheel (using $1.9 < \eta < 2.1$)

Energy (GeV)	Custom solid (s)	New EMEC (s)	Difference (%)
2	1.5	1.4	-7%
20	11.9	9.8	-21%
200	158.5	106.4	-33%

Table: Comparison of CPU time requirements between the custom solid and the non-twisted trapezoid representations in the outer wheel

Results with non-twisted trapezoids - outer wheel

- In the outer wheel:
- The agreement in the number of tracks is within 2% for low energies and gradually reduces for higher energies.
- At low energies more steps are being simulated ($\sim$ 3% at 20 GeV), and at high energies less are being simulated.

Analysis of results

- Some additional callgrind profiling was done.
- For a typical full detector simulation, $\sim$ 24% of the navigation time is taken by the method ComputeStep(), which calls the DistanceToIn() and DistanceToOut() methods.
- For non-twisted trapezoids, the ComputeStep() method consumes $\sim$ 19% of the navigation time.
- $\sim$ 24% of this time is consumed in the DistanceToIn() and DistanceToOut() methods.
- These methods are therefore a factor of 4 faster than the equivalent twisted trapezoid methods.

Next steps

- Geant4 now contains an additional solid, known as a generic trapezoid.
- This can represent a twisted trapezoid with approximated surfaces.
- This surface approximation allows for faster computation time.
- By tuning the number of radial sections used, this solid could potentially approximate the absorber geometry very well.
- This solid will be implemented in the new EMEC description by replacing the twisted trapezoid.
- Performance tests shall again be carried out.

Next steps

- Another improvement could be made by modifying the way the absorbers are placed in the wheel.
- By placing sections directly into the wheel, rather than through nested volumes and divisions (as in Geant3), a small performance improvement may be gained.
- This would also permit variations in the positioning of individual absorber layers to be modelled, e.g. detector sagging.

Summary

- New Geant4 EMEC geometry was developed using twisted trapezoid solids.
- The simulation performance of this geometry was found to be slower than the custom solid EMEC.
- The most promising method to improve this is to simplify the description of the twisted surfaces (Generic Trapezoid).
- More sections of this solid may be used to tune to the required accuracy of the description.
- An implementation shall now be developed and tested using these generic trapezoids.

Acknowledgements

- John Apostolakis, and Andrea Dell'Acqua

References

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