Frozen Showers

fast simulation of electromagnetic showers in the ATLAS LAr EM calorimeter

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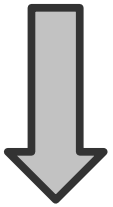
1. Fast Simulation

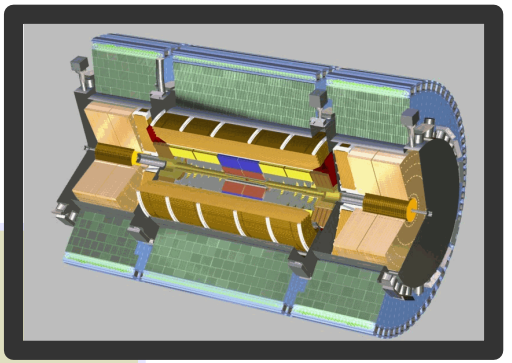
Many physics analysis need a considerable number of simulated events and the full simulation approach turn out to be too slow.
An alternative to full simulation can be found in the *frozen showers* approach.



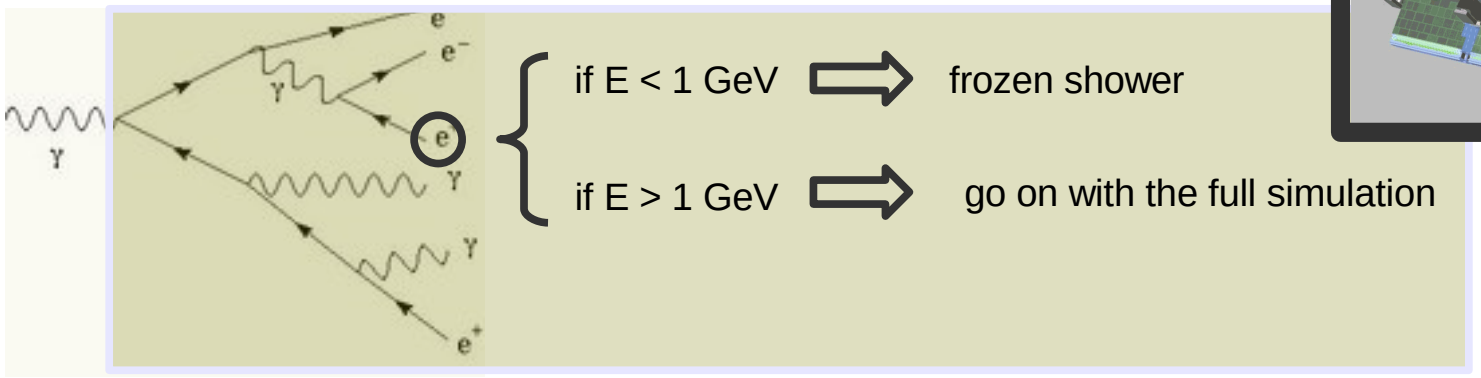
The idea of this project is to speed up simulation keeping most of the simulation details.

1.1 Frozen Showers

The fast simulation mainly works on low energy electrons, which means below 1 GeV.
The approach is as follows.
In the simulation prestored shower templates, called *frozen showers (FS)*, are used to substitute the simulation of low energy electromagnetic particles (Geant4).



EM Calorimeter

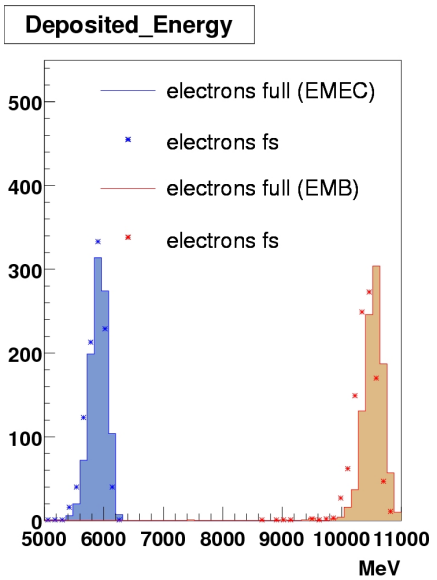


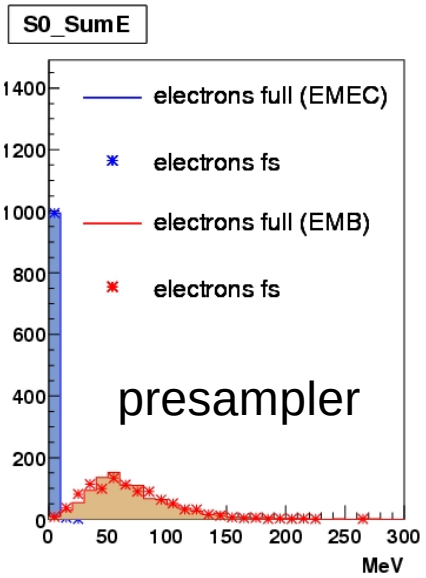
The FS templates are stored in libraries (the *electron library* and the *photon library*).

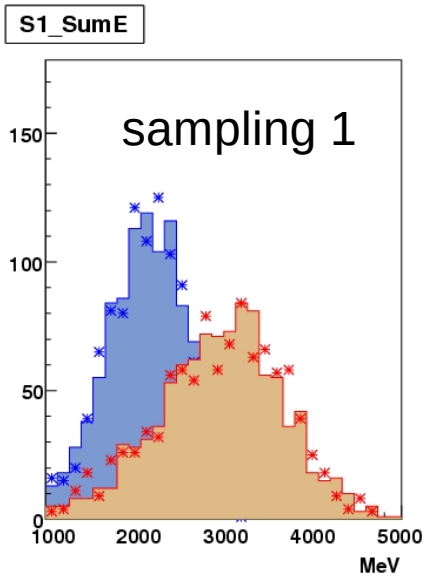
Performance of electron FS library (FS Lib)

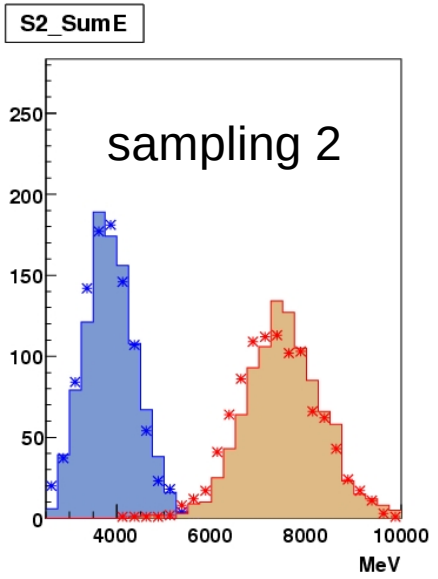
2.1 Performance of the electron FS Lib

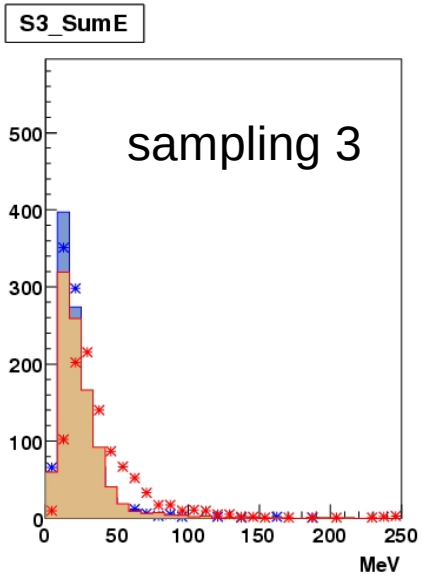
High energy **electrons**
(64 GeV)









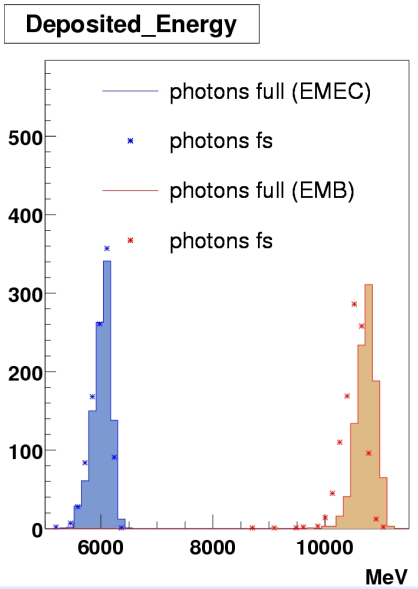


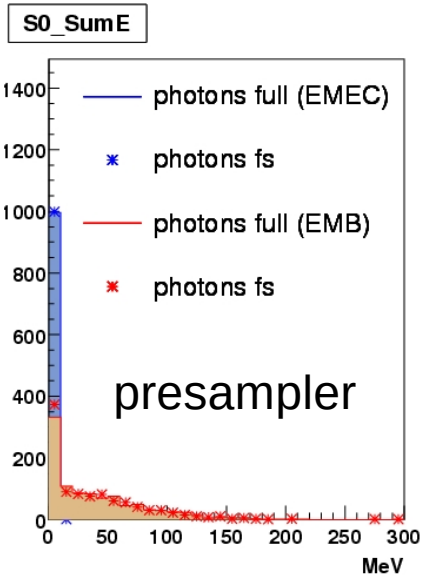
Average time per event	EMEC	EMB
Full Simulation	32.5 s	12.0 s
Frozen Shower	1.3 s	0.7 s
Improvement in speed	**95%**	**94%**

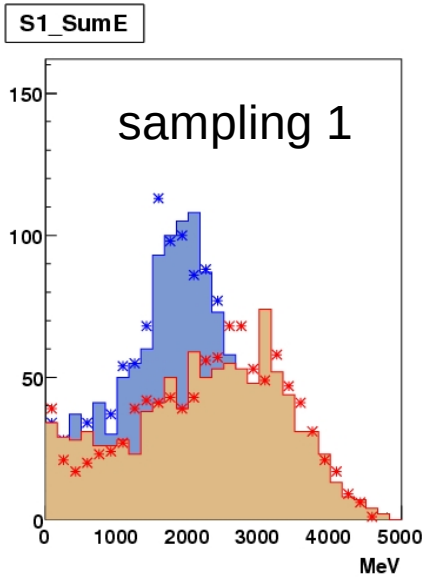
Deposited energy (MeV)	EMEC	EMB
Full Simulation	5904	10524
Frozen Shower	5857	10422
Difference	**0.8%**	**1.0%**

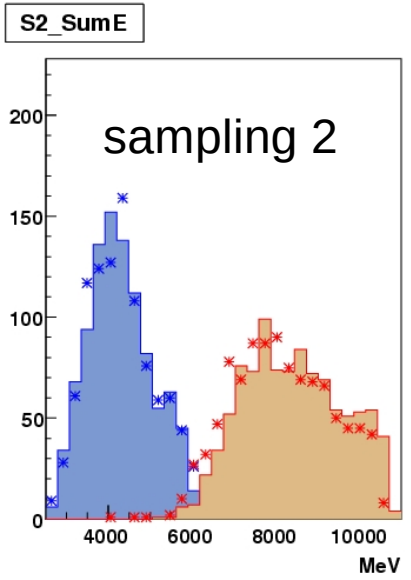
2.2 Performance of the electron FS Lib

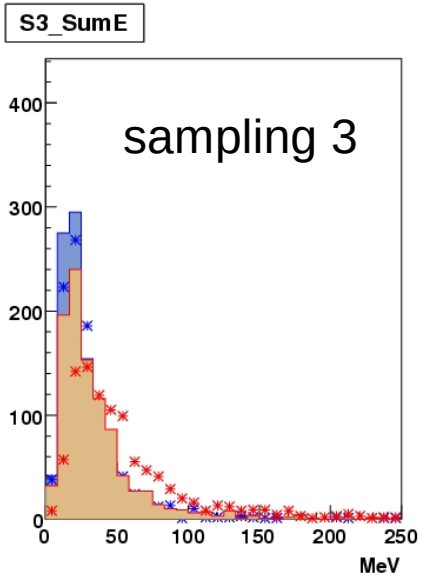
High energy **photons**
(64 GeV)









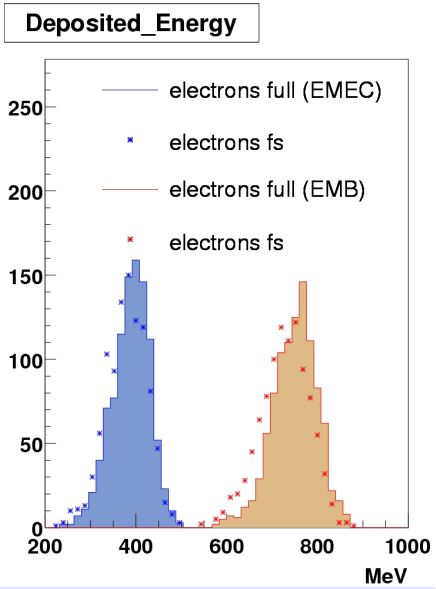


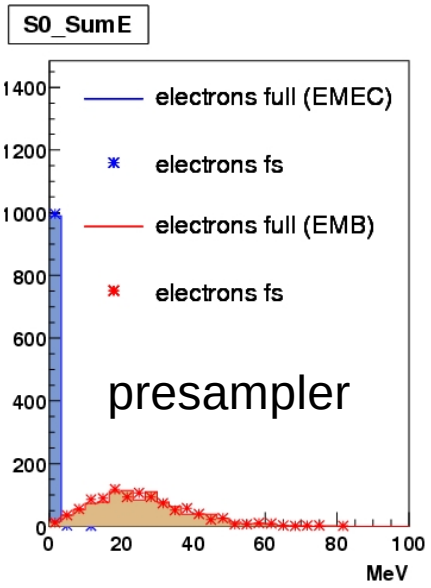
Average time per event	EMEC	EMB
Full Simulation	32.6 s	18.0 s
Frozen Shower	0.9 s	0.4 s
Improvement in speed	**97%**	**97%**

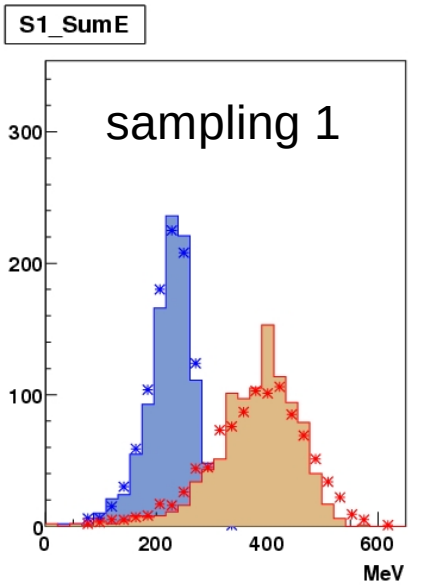
Deposited energy (MeV)	EMEC	EMB
Full Simulation	6009	10731
Frozen Shower	5983	10506
Difference	**0.4%**	**2.1%**

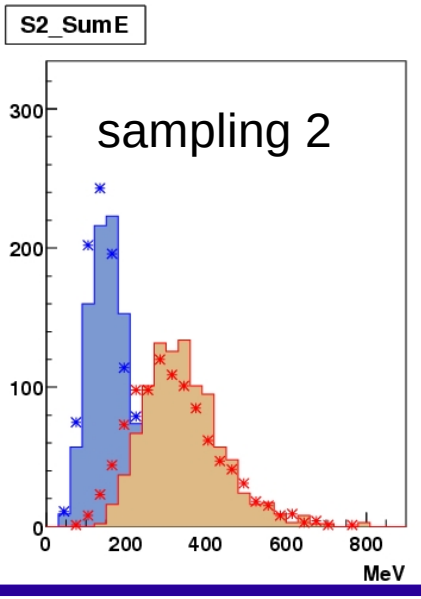
2.3 Performance of the electron FS Lib

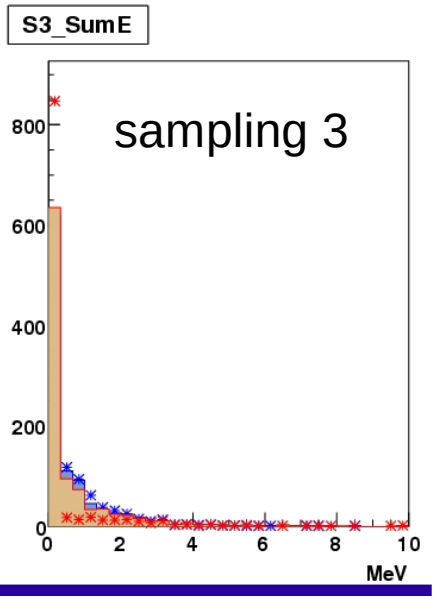
Low energy **electrons**
(5 GeV)









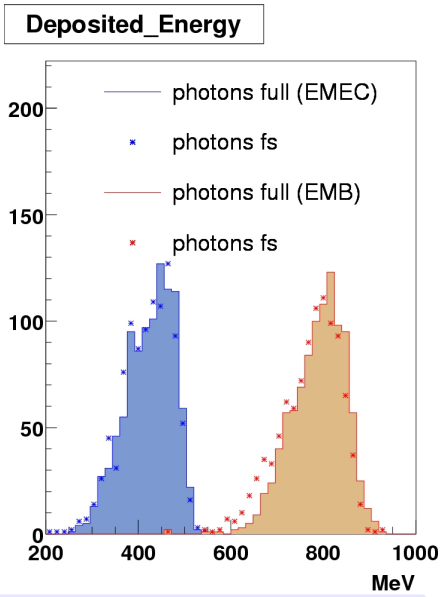


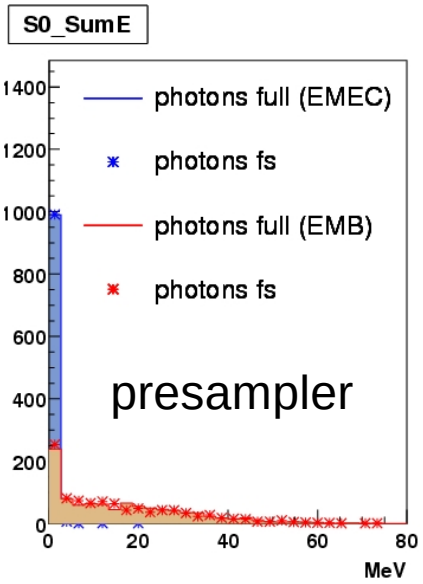
Average time per event	EMEC	EMB
Full Simulation	2.5 s	1.2 s
Frozen Shower	0.4 s	0.3 s
Improvement in speed	**82.8%**	**74.6%**

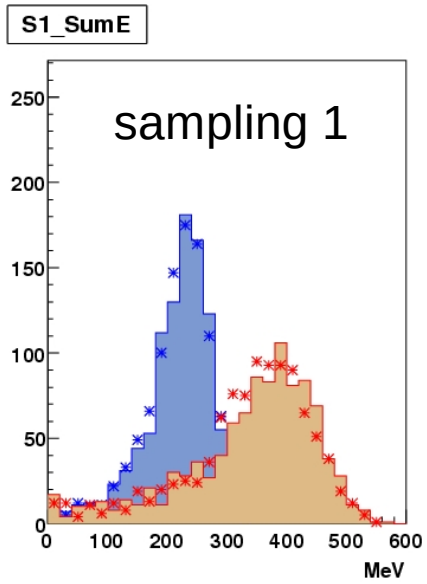
Deposited energy (MeV)	EMEC	EMB
Full Simulation	388	750
Frozen Shower	379	727
Difference	**2.3%**	**3.1%**

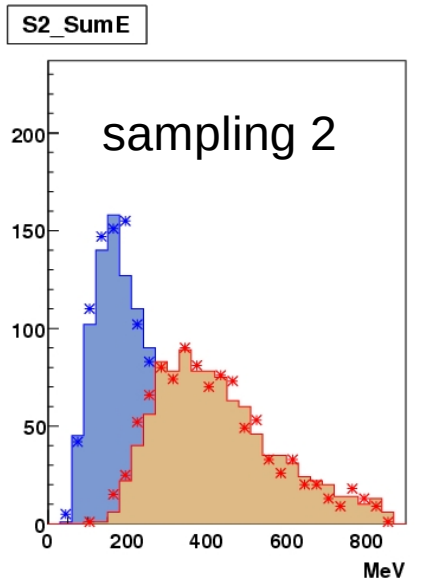
2.4 Performance of the electron FS Lib

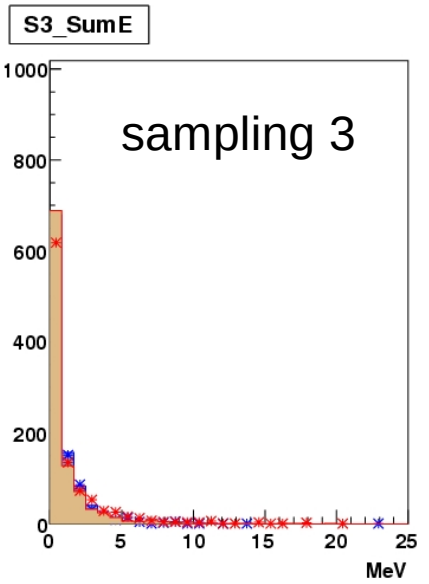
Low energy **photons**
(5 GeV)











Average time per event	EMEC	EMB
Full Simulation	2.5 s	1.0 s
Frozen Shower	0.2 s	0.1 s
Improvement in speed	**90%**	**86%**

Deposited energy (MeV)	EMEC	EMB
Full Simulation	423	788
Frozen Shower	419	770
Difference	**0.9%**	**2.3%**

2.5 Performance of the electron FS Lib

Average time per event	EMEC	---
Full Simulation	0.5 s	
Frozen Shower	0.4 s	
Improvement in speed	**19.5%**	

Average time per event	EMEC	---
Full Simulation	0.3 s	
Frozen Shower	0.2 s	
Improvement in speed	**13.8%**	

Deposited energy (MeV)	EMEC	---
Full Simulation	177	
Frozen Shower	174	
Difference	**1.7%**	

Deposited energy (MeV)	EMEC	---
Full Simulation	131	
Frozen Shower	127	
Difference	**3.0%**	

Average time per event	EMEC	---
Full Simulation	32.53 s	
Frozen Shower	1.20 s	
Improvement in speed	**96.3 %**	

HIGH ENERGY MUONS (64 GeV)

Deposited energy (MeV)	EMEC	---
Full Simulation	5945	
Frozen Shower	5904	
Energy lost	**0.7 %**	

Average time per event	EMEC	---
Full Simulation	2.44 s	
Frozen Shower	0.33 s	
Improvement in speed	**86.5 %**	

LOW ENERGY MUONS (5 GeV)

Deposited energy (MeV)	EMEC	---
Full Simulation	397	
Frozen Shower	396	
Energy lost	**0.2 %**	

2.6 Performance of the electron FS Lib

Average time per event	EMEC	---
Full Simulation	0.46 s	
Frozen Shower	0.37 s	
Improvement in speed	**19.5 %**	

HIGH ENERGY Neutral PIONS (64 GeV)

Deposited energy (MeV)	EMEC	---
Full Simulation	177	
Frozen Shower	174	
Energy lost	**1.7 %**	

Average time per event	EMEC	---
Full Simulation	0.29 s	
Frozen Shower	0.25 s	
Improvement in speed	**13.8 %**	

LOW ENERGY Neutral PIONS (5 GeV)

Deposited energy (MeV)	EMEC	---
Full Simulation	131	
Frozen Shower	127	
Energy lost	**3.0 %**	

Average time per event	EMEC	---
Full Simulation	32.5 s	
Frozen Shower	1.2 s	
Improvement in speed	**96.3%**	

Deposited energy (MeV)	EMEC	---
Full Simulation	5945	
Frozen Shower	5904	
Difference	**0.7%**	

Average time per event	EMEC	---
Full Simulation	2.4 s	
Frozen Shower	0.3 s	
Improvement in speed	**86.5%**	

Deposited energy (MeV)	EMEC	---
Full Simulation	397	
Frozen Shower	396	
Difference	**0.2%**	

Performance of electron and photon FS Lib

3.1 Barrel Calorimeter (EMB)

electrons

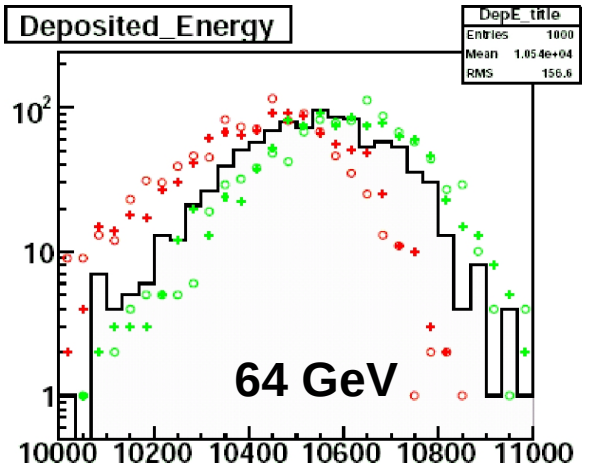
fs1: electron FS Lib

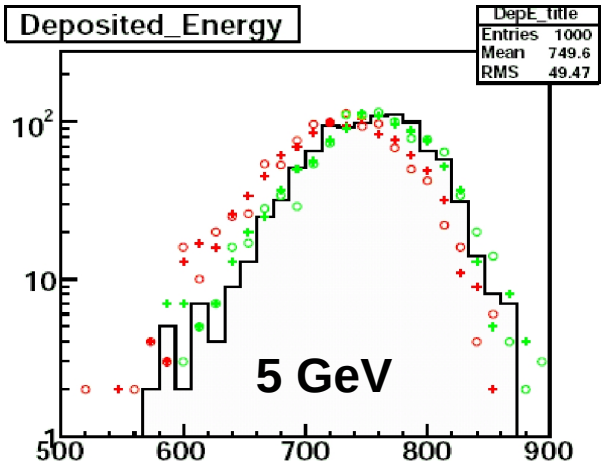
fs3: electron and photon FS Lib

64 Gev	*time*	*Deposited Energy*	*number of hits*
full	12.023 +- 0.012	10524.7	583
fs1	0.671 +- 0.009	10422.1	327
fs1, kill(false)	0.692 +- 0.009	10396.3	267
fs3	0.507 +- 0.009	10575.2	270
fs3, kill(false)	0.503 +- 0.008	10585.8	222

5 Gev	*time*	*Deposited Energy*	*number of hits*
full	1.180 +- 0.005	749.6	158
fs1	0.302 +- 0.005	726.7	120
fs1, kill(false)	0.307 +- 0.006	724.3	88
fs3	0.266 +- 0.004	748.0	115
fs3, kill(false)	0.270 +- 0.004	752.1	91

fs* kill(false) means FS down to 1 MeV



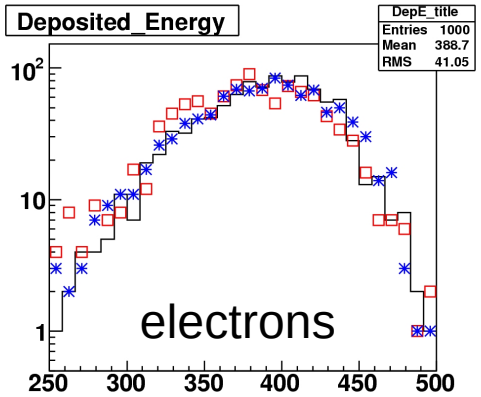


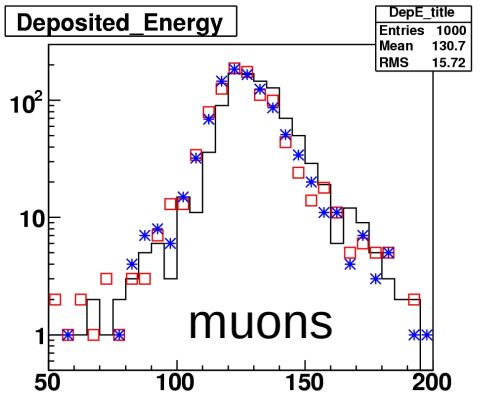
The photon library improves the simulation time of **25%** for high energy and of **12%** for low energy electrons.

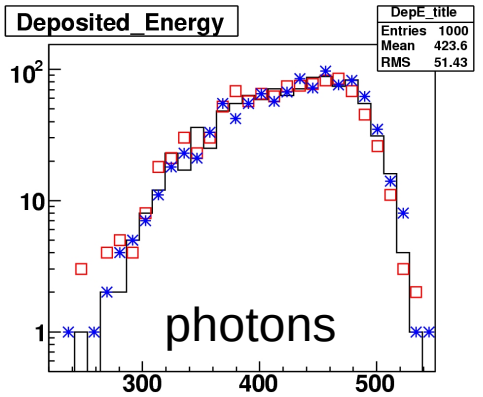
3.2 End Cap Calorimeter (EMEC)

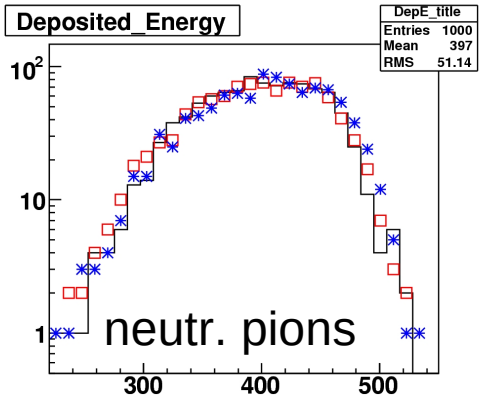
Low energy particles 1: electron FS Lib 3: electron and photon FS Lib

Particle Energy: 5 GeV. Detector: EMEC ($\eta = 2.0$)				
	e^-	μ^-	γ	π^o
option	timing (s)	timing (s)	timing (s)	timing (s)
F	2.50 ± 0.00	0.29 ± 0.00	2.52 ± 0.00	2.44 ± 0.00
1	0.43 ± 0.01	0.25 ± 0.00	0.24 ± 0.01	0.33 ± 0.01
3	0.35 ± 0.00	0.25 ± 0.00	0.18 ± 0.01	0.28 ± 0.01
g(3)	25.5%	0.0%	28.0%	15.1%
option	dep.en.(MeV)	dep.en.(MeV)	dep.en.(MeV)	dep.en.(MeV)
F	388 ± 1	131 ± 0	423 ± 2	397 ± 2
1	379 ± 1	127 ± 1	419 ± 2	396 ± 2
3	387 ± 1	127 ± 0	426 ± 2	401 ± 2
s(F,1)	2.3%	3.0%	0.9%	0.2%
s(F,3)	0.3%	3.0%	−0.7%	−1.0%





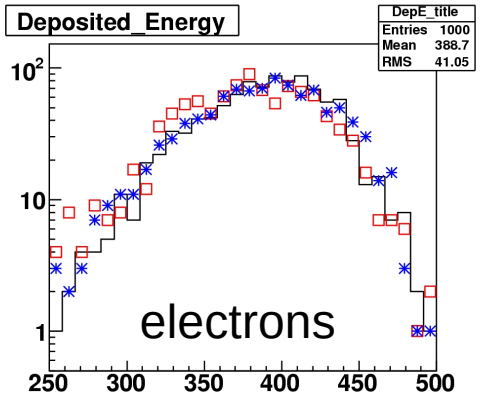


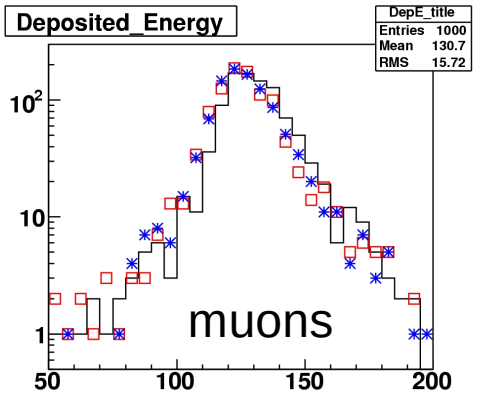


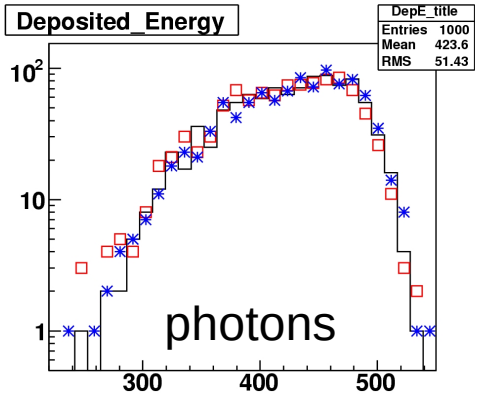
3.3 End Cap Calorimeter (EMEC)

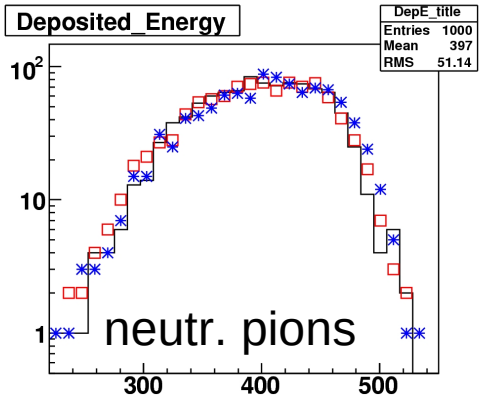
High energy particles 1: electron FS Lib 3: electron and photon FS Lib

Particle Energy: 64 GeV. Detector: EMEC ($\eta = 2.0$)				
	e^-	μ^-	γ	π^o
option	timing (s)	timing (s)	timing (s)	timing (s)
F	32.48 ± 0.02	0.46 ± 0.01	32.63 ± 0.03	32.53 ± 0.02
1	1.33 ± 0.01	0.37 ± 0.01	0.94 ± 0.02	1.20 ± 0.02
3	0.80 ± 0.01	0.36 ± 0.01	0.51 ± 0.02	0.68 ± 0.02
g(3)	40.7%	0.0%	46.3%	43.3%
option	dep.en.(MeV)	dep.en.(MeV)	dep.en.(MeV)	dep.en.(MeV)
F	5904 ± 5	174 ± 3	6009 ± 6	5945 ± 5
1	5857 ± 5	177 ± 4	5983 ± 5	5904 ± 6
3	5917 ± 5	180 ± 4	6027 ± 6	5956 ± 6
s(F,1)	0.8%	−1.7%	0.4%	0.7%
s(F,3)	−0.2%	−3.4%	−0.3%	−0.2%









4. Summary

- the frozen showers approach is showing good performance and agreement with full simulation;
- the introduction of new template (the "*photon library*") improves the simulation time and reduces the difference in energy;