Version 10.5

Fast Simulation

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Geant4 Advanced Course @ CERN

March 26–27, 2019

Outline

1. Why do we need fast simulation?
2. How to use it in Geant4
   - where
   - what
   - how

   } to parametrise
3. Short summary
4. Examples

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   } to parametrise
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example link to code in G4 v10.5

```
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```

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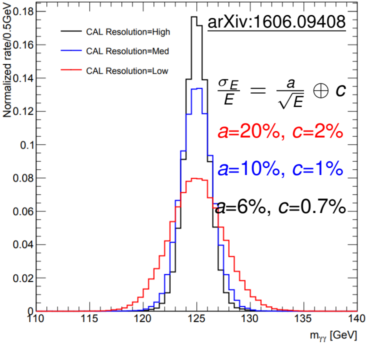

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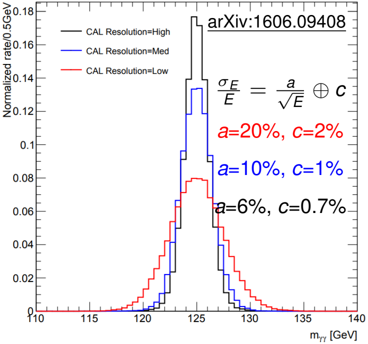

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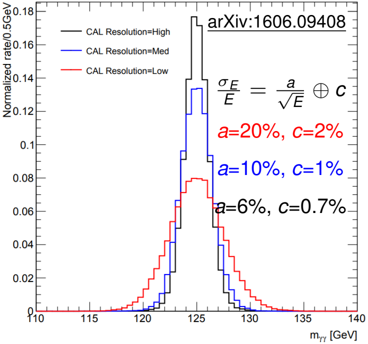

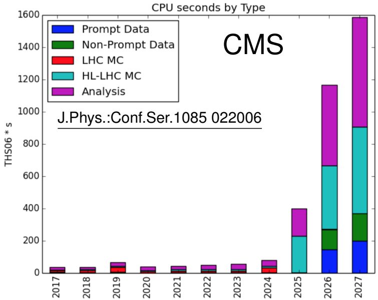

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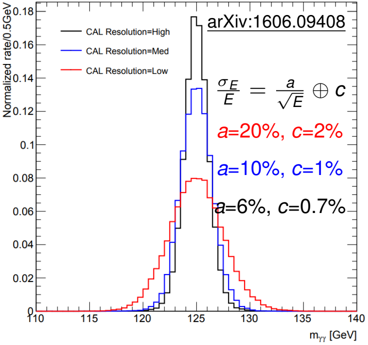

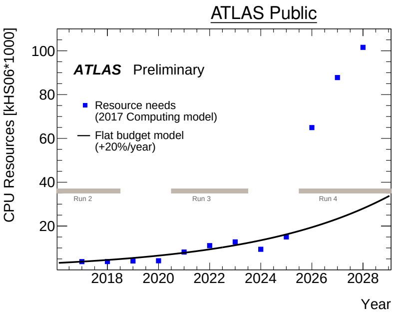

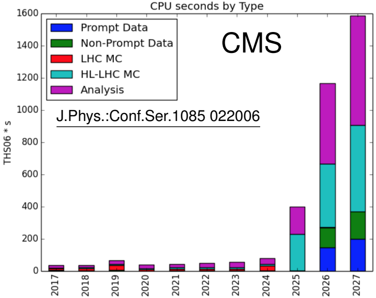

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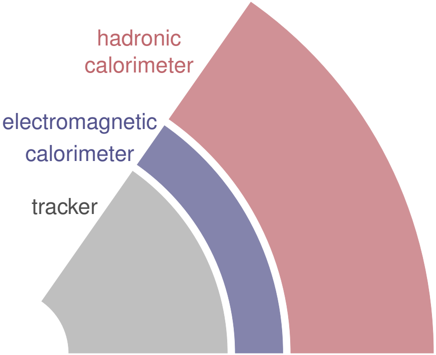

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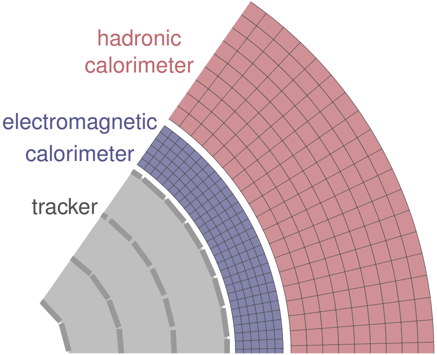

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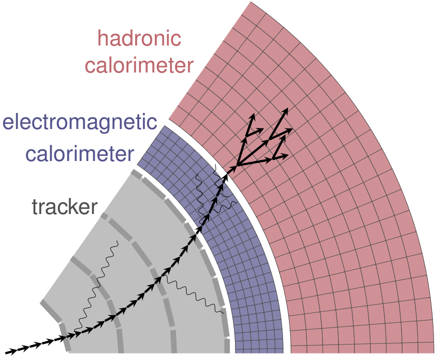

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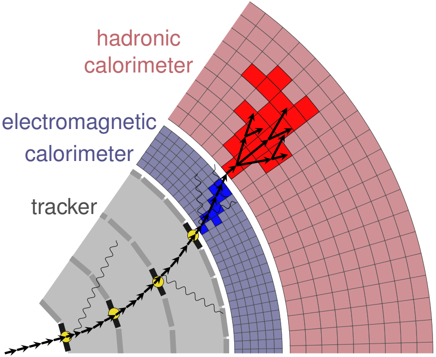

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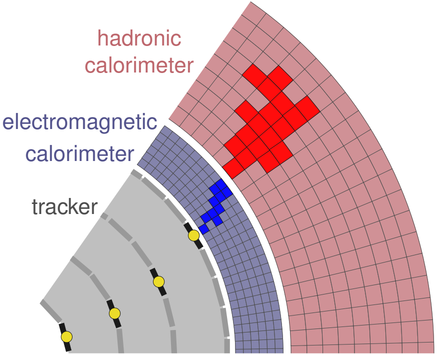

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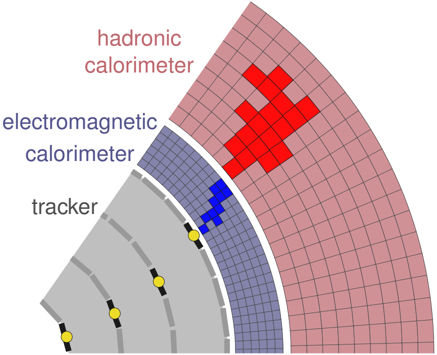

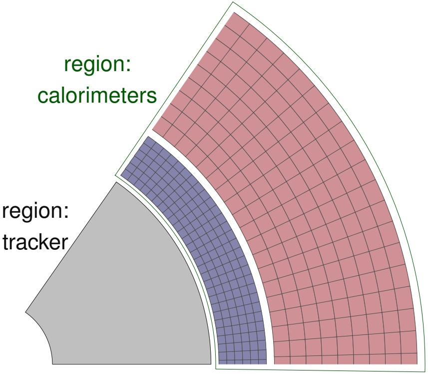

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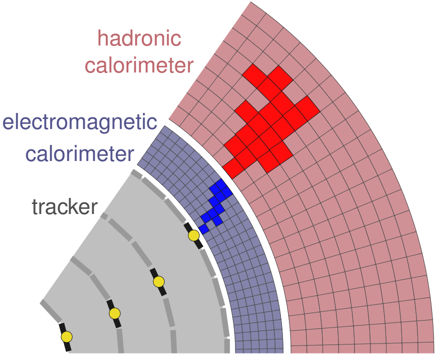

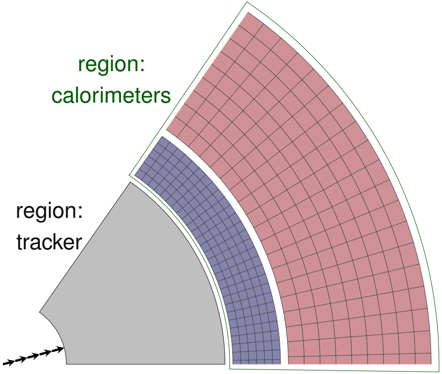

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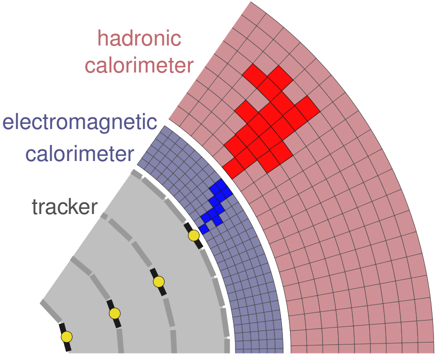

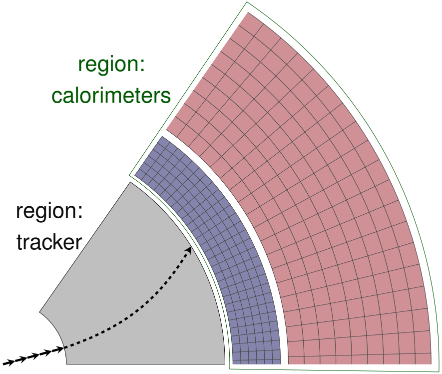

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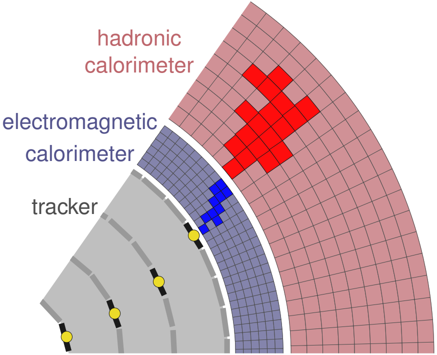

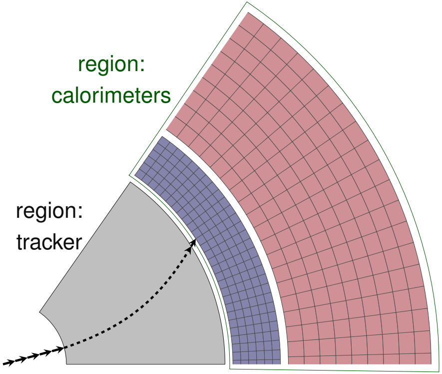

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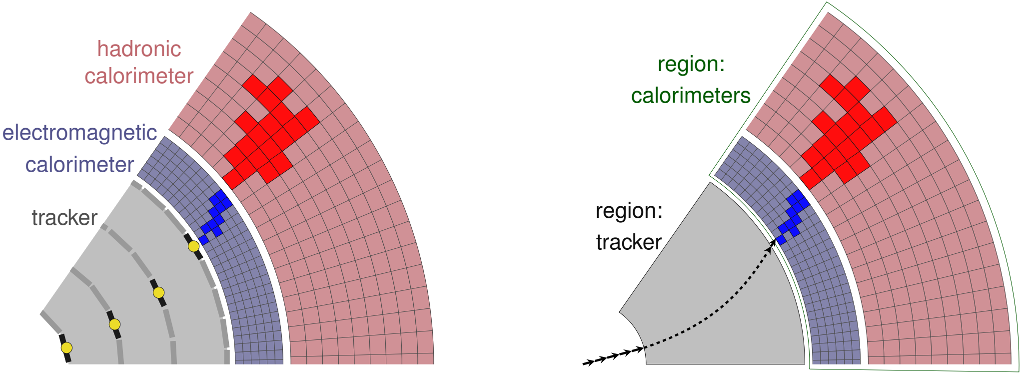

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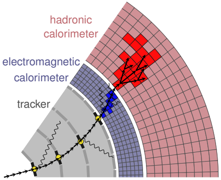

detailed / “full” simulation

- detailed detector description
- definitions of particles and processes
- transport in e-m field

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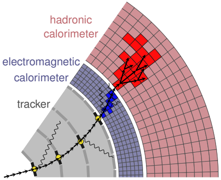
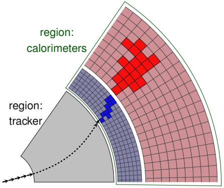


detailed / "full" simulation

parametrisation / "fast" simulation



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- which particles
- how/what happens

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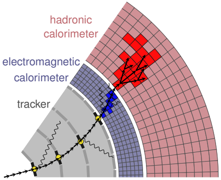

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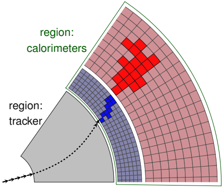

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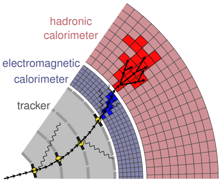

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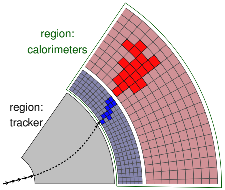

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Defining both ‘full’ and ‘fast’ simulation within one framework (Geant4) offers great flexibility to seamlessly mix both types.

Where?

Parametrisation may be realised within:

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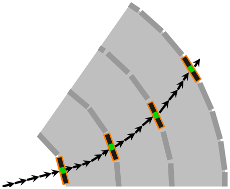
sub-volume

(many volumes)



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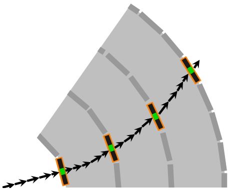
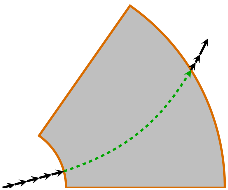


detector envelope (single volume)



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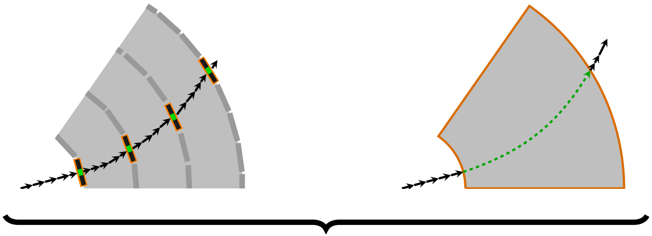

"mass" geometry

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Parametrisation may be realised within:

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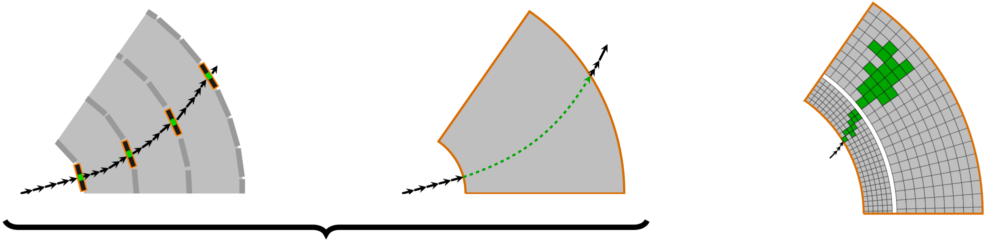

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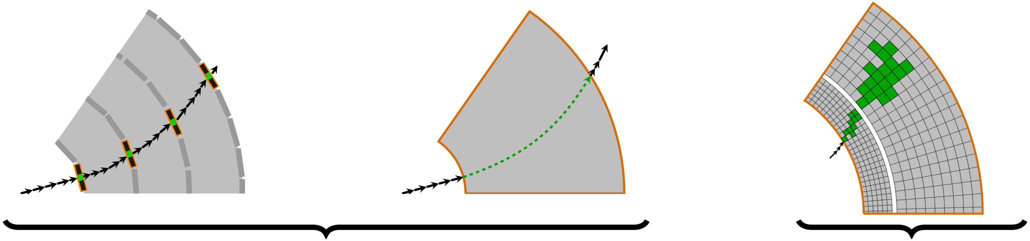

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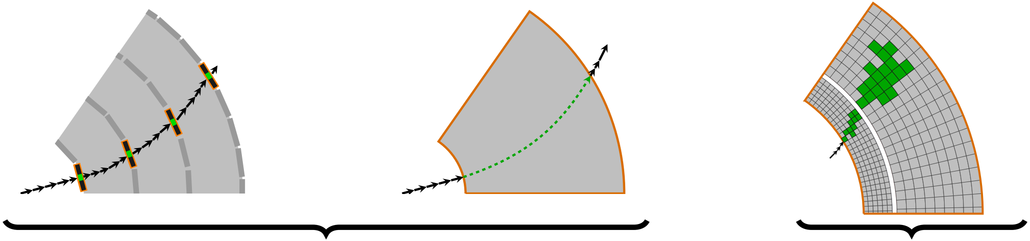

“mass” geometry | parallel geometry

Fast simulation in Geant4 is attached to **G4Region**
(associated to root G4LogicalVolume in either mass or parallel geometry).

G4Region (envelope)

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for mass geometry: examples/extended/parameterisations/Par01/src/Par01DetectorConstruction.cc

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G4Region* caloRegion = new G4Region("EM_calo_region");
caloRegion->AddRootLogicalVolume(calorimeterLog); // calorimeterLog is a G4LogicalVolume
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for parallel geometry: examples/extended/parameterisations/Par01/src/Par01ParallelWorldForPion.cc

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  G4Region* ghostRegion = new G4Region("GhostCalorimeterRegion");
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G4FastSimulationPhysics helps to add parametrisation process on top of any other physics list (which is used where parametrisation is not invoked).

(since v10.3, for older versions consult user's guide or slide 25)

G4FastSimulationPhysics

for mass and parallel geometry:

examples/extended/parameterisations/Par01/examplePar01.cc

```
FTFP_BERT* physicsList = new FTFP_BERT; // G4VModularPhysicsList
G4FastSimulationPhysics* fastSimulationPhysics = new G4FastSimulationPhysics(); // helper
fastSimulationPhysics->BeVerbose();
// -- activation of fast simulation for particles having fast simulation models attached in the mass geometry:
fastSimulationPhysics->ActivateFastSimulation("e-");
fastSimulationPhysics->ActivateFastSimulation("e+");
fastSimulationPhysics->ActivateFastSimulation("gamma");
// -- activation of fast simulation for particles having fast simulation models attached in the parallel geometry:
fastSimulationPhysics->ActivateFastSimulation("pi+","pionGhostWorld");
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  - check particle type or intrinsic information (from G4ParticleDefinition)
  - check dynamic conditions (from G4FastTrack)
    - energy, momentum, direction, ... (from G4Track)

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  implementation of G4VFastSimulationModel class;

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Parametrisation trigger needs to be set in implementation of **G4VFastSimulationModel**,

Which particles?

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  G4Region attached to G4LogicalVolume and linked to implementation of G4VFastSimulationModel;

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  implementation of G4VFastSimulationModel class;

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Parametrisation trigger needs to be set in implementation of **G4VFastSimulationModel**, which is added to **G4Region**.

G4VFastSimulationModel (1/4)

Core of the parametrisation:

- **which** particles
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```

examples/extended/parameterisations/Par01/src/Par01DetectorConstruction.cc

```
G4RegionStore* regionStore = G4RegionStore::GetInstance();

G4Region* caloRegion = regionStore->GetRegion("EM_calo_region");
// builds a model and sets it to the envelope of the calorimeter:
new Par01EMShowerModel("emShowerModel",caloRegion);
```

G4VFastSimulationModel (1/4)

Core of the parametrisation:

- which particles
- how/what happens

```
// constructor adds this model to G4FastSimulationManager of given envelope
G4VFastSimulationModel(const G4String&, G4Region*)
```

examples/extended/parameterisations/Par01/src/Par01DetectorConstruction.cc

```
G4RegionStore* regionStore = G4RegionStore::GetInstance();

G4Region* caloRegion = regionStore->GetRegion("EM_calo_region");
// builds a model and sets it to the envelope of the calorimeter:
new Par01EMShowerModel("emShowerModel",caloRegion);
```

G4VFastSimulationModel (2/4) — which particles?

Check intrinsic particle information (mass, charge, spin, quark content, ...)

```
virtual G4bool G4VFastSimulationModel::IsApplicable  (const G4ParticleDefinition&) = 0
```

G4VFastSimulationModel (2/4) — which particles?

Check intrinsic particle information (mass, charge, spin, quark content, ...)

```
virtual G4bool G4VFastSimulationModel::IsApplicable  (const G4ParticleDefinition&) = 0
```

Par01EMShowerModel.cc

```
G4bool Par01EMShowerModel::IsApplicable(const
↪   G4ParticleDefinition& particleType)
{



                                                          }
}
```

Par01PionShowerModel.cc

```
G4bool Par01PiModel::IsApplicable(const
↪   G4ParticleDefinition& particleType)
{



}
```

Par02FastSimModelTracker.cc

```
G4bool Par02FastSimModelTracker::IsApplicable( const
↪   G4ParticleDefinition& aParticleType ) {

}
```

G4VFastSimulationModel (2/4) — which particles?

Check intrinsic particle information (mass, charge, spin, quark content, ...)

```
virtual G4bool G4VFastSimulationModel::IsApplicable  (const G4ParticleDefinition&) = 0
```

Par01EMShowerModel.cc

```
G4bool Par01EMShowerModel::IsApplicable(const
↪   G4ParticleDefinition& particleType)
{
  return
    &particleType ==
    ↪   G4Electron::ElectronDefinition() ||
    &particleType ==
    ↪   G4Positron::PositronDefinition() ||
    &particleType == G4Gamma::GammaDefinition();
}
```

Par01PionShowerModel.cc

```
G4bool Par01PiModel::IsApplicable(const
↪   G4ParticleDefinition& particleType)
{
  return
    &particleType ==
    ↪   G4PionMinus::PionMinusDefinition() ||
    &particleType ==
    ↪   G4PionPlus::PionPlusDefinition();
}
```

Par02FastSimModelTracker.cc

```
G4bool Par02FastSimModelTracker::IsApplicable( const
↪   G4ParticleDefinition& aParticleType ) {

}
```

G4VFastSimulationModel (2/4) — which particles?

Check intrinsic particle information (mass, charge, spin, quark content, ...)

```
virtual G4bool G4VFastSimulationModel::IsApplicable  (const G4ParticleDefinition&) = 0
```

Par01EMShowerModel.cc

```
G4bool Par01EMShowerModel::IsApplicable(const
  G4ParticleDefinition& particleType)
{
  return
    &particleType ==
      G4Electron::ElectronDefinition() ||
    &particleType ==
      G4Positron::PositronDefinition() ||
    &particleType == G4Gamma::GammaDefinition();
}
```

Par01PionShowerModel.cc

```
G4bool Par01PiModel::IsApplicable(const
  G4ParticleDefinition& particleType)
{
  return
    &particleType ==
      G4PionMinus::PionMinusDefinition() ||
    &particleType ==
      G4PionPlus::PionPlusDefinition();
}
```

Par02FastSimModelTracker.cc

```
G4bool Par02FastSimModelTracker::IsApplicable( const
  G4ParticleDefinition& aParticleType ) {
  return aParticleType.GetPDGCharge() != 0;  // Applicable
    for all charged particles
}
```

G4VFastSimulationModel (3/4) — which particles?

Check dynamic conditions (momentum, direction, position, distance to boundary, ...)

```
virtual G4bool G4VFastSimulationModel::ModelTrigger  (const G4FastTrack&) = 0
```

G4VFastSimulationModel (3/4) — which particles?

Check dynamic conditions (momentum, direction, position, distance to boundary, ...)

```
virtual G4bool G4VFastSimulationModel::ModelTrigger  (const G4FastTrack&) = 0
```

Par01PionShowerModel.cc

```
G4bool Par01EMShowerModel::ModelTrigger(const G4FastTrack& fastTrack)
{
  // Applies the parameterisation above 100 MeV:
  return fastTrack.GetPrimaryTrack()->GetKineticEnergy() > 100*MeV;
}
```

G4VFastSimulationModel (3/4) — which particles?

Check dynamic conditions (momentum, direction, position, distance to boundary, ...)

```
virtual G4bool G4VFastSimulationModel::ModelTrigger  (const G4FastTrack&) = 0
```

Par01PionShowerModel.cc

```
G4bool Par01EMShowerModel::ModelTrigger(const G4FastTrack& fastTrack)
{
  // Applies the parameterisation above 100 MeV:
  return fastTrack.GetPrimaryTrack()->GetKineticEnergy() > 100*MeV;
}
```

Par01PiModel.cc

```
G4bool Par01PiModel::ModelTrigger(const G4FastTrack& fastTrack) {
  // -- example -- position:
  fastTrack.GetPrimaryTrack()->GetPosition() // global coord.
  fastTrack.GetPrimaryTrackLocalPosition() // envelope coord.
  // -- example -- direction:
  fastTrack.GetPrimaryTrack()->GetMomentum().unit() // global
  fastTrack.GetPrimaryTrackLocalDirection() // envelope
  return true;
}
```

G4VFastSimulationModel (3/4) — which particles?

Check dynamic conditions (momentum, direction, position, distance to boundary, ...)

```
virtual G4bool G4VFastSimulationModel::ModelTrigger  (const G4FastTrack&) = 0
```

GFlashShowerModel.cc

```
G4bool GFlashShowerModel::ModelTrigger(const G4FastTrack & fastTrack )

{
  G4bool select = false;
  if(FlagParamType != 0)
  {
    G4double  ParticleEnergy = fastTrack.GetPrimaryTrack()->GetKineticEnergy();
    G4ParticleDefinition &ParticleType =
      *(fastTrack.GetPrimaryTrack()->GetDefinition());
    if(ParticleEnergy > PBound->GetMinEneToParametrise(ParticleType) &&
       ParticleEnergy < PBound->GetMaxEneToParametrise(ParticleType) )
    {
      // check conditions depending on particle flavour
      // performance to be optimized @@@@@@@
      Parameterisation->GenerateLongitudinalProfile(ParticleEnergy);
      select     = CheckParticleDefAndContainment(fastTrack);
      if (select) EnergyStop= PBound->GetEneToKill(ParticleType);
    }
  }
  return select;
}
```

G4VFastSimulationModel (4/4) – What happens?

Once particle is in a chosen volume, fulfils all conditions
– take over tracking within volume and decide what to do, e.g.:

- alter energy
- move to different position (e.g. exit from volume)
- create energy deposit(s)
- kill particle
- create secondaries

```
virtual G4bool G4VFastSimulationModel::DoIt(const G4FastTrack&, G4FastStep&) = 0
```

G4VFastSimulationModel (4/4) – What happens?

Once particle is in a chosen volume, fulfils all conditions
– take over tracking within volume and decide what to do, e.g.:

- alter energy
- move to different position (e.g. exit from volume)
- create energy deposit(s)
- kill particle
- create secondaries

```
virtual G4bool G4VFastSimulationModel::DoIt(const G4FastTrack&, G4FastStep&) = 0
```

input information: G4FastTrack

output information: G4FastStep

Summary: fast simulation in Geant4

Step-by-step:

Summary: fast simulation in Geant4

Step-by-step:

1. Implement model that specifies **which** particles, under what conditions and **how** should be parameterised

Summary: fast simulation in Geant4

Step-by-step:

1. Implement model that specifies **which** particles, under what conditions and **how** should be parameterised
   user's implementation of **G4VFastSimulationModel**

Summary: fast simulation in Geant4

Step-by-step:

1. Implement model that specifies **which** particles, under what conditions and **how** should be parameterised
   user's implementation of **G4VFastSimulationModel**
2. Register the parameterisation(s) for the particles (**which**)

Summary: fast simulation in Geant4

Step-by-step:

1. Implement model that specifies **which** particles, under what conditions and **how** should be parameterised
   user's implementation of **G4VFastSimulationModel**
2. Register the parameterisation(s) for the particles (**which**)
   by adding to physics list **G4FastSimulationManagerProcess** and activating it for certain particles

Summary: fast simulation in Geant4

Step-by-step:

1. Implement model that specifies **which** particles, under what conditions and **how** should be parameterised
   user's implementation of **G4VFastSimulationModel**
2. Register the parameterisation(s) for the particles (**which**)
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3. Specify **where** parametrisation takes place

Summary: fast simulation in Geant4

Step-by-step:

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3. Specify **where** parametrisation takes place
   by creating **G4Region**, attaching a root G4LogicalVolume, and passing it to a constructor of implementation of G4VFastSimulationModel

Summary: fast simulation in Geant4

Step-by-step:

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Existing examples: `examples/extended/parameterisations/`

Messenger

Fast simulation messenger

```
/param/ // Fast Simulation print/control commands.
/param/showSetup // Show fast simulation setup (for each world: fast simulation manager
↪  process - which particles, region hierarchy - which models)
/param/listEnvelopes <ParticleName (default:all)> // List all the envelope names for a
↪  given particle (or for all particles if without parameters).
/param/listModels <EnvelopeName (default:all)> // List all the Model names for a given
↪  envelope (or for all envelopes if without parameters).
/param/listIsApplicable <ModelName (default:all)> // List all the Particle names a given
↪  model is applicable (or for all models if without parameters).
/param/ActivateModel <ModelName> // Activate a given Model.
/param/InActivateModel <ModelName> // InActivate a given Model.
```

Examples

Examples

Existing examples: `examples/extended/parameterisations/`

- `examples/extended/parameterisations/Par01/src/`
  - `Par01EMShowerModel.cc`
  - `Par01PionShowerModel.cc`
  - `Par01PiModel.cc`
- `examples/extended/parameterisations/Par02/src/`
  - `Par02FastSimModelEMCal.cc`
  - `Par02FastSimModelHCal.cc`
  - `Par02FastSimModelTracker.cc`
- `GFlashShowerModel`

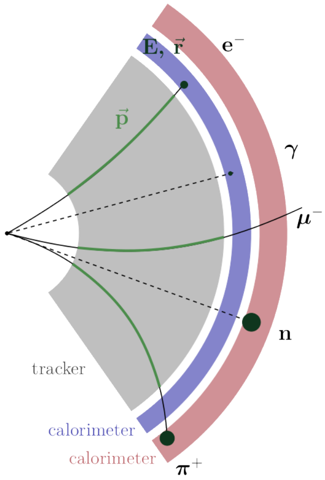
Example 1:

`examples/extended/parameterisations/Par02`

Example 1

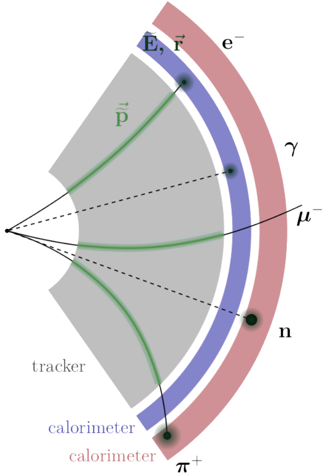
- Simple parametrisation

Example 1



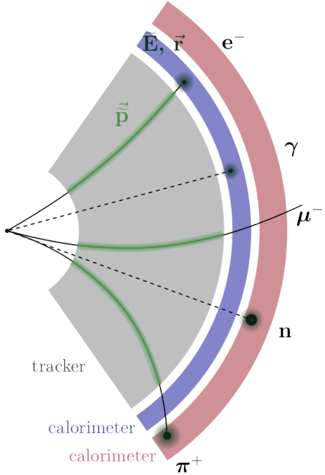
- Simple parametrisation

Example 1



- Simple parametrisation
- Smearing of the momentum in the tracker and energy in the calorimeter

Example 1



- Simple parametrisation
- Smearing of the momentum in the tracker and energy in the calorimeter
- User input: detector resolution;

$$\sigma_{p_T} = 1.3\%$$

$$\sigma_E = \frac{110\%}{\sqrt{E}} \oplus 9\%$$

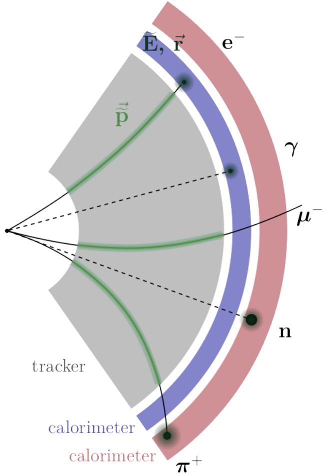
Example 1

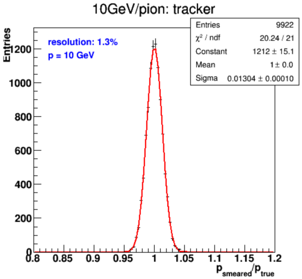
examples/extended/parameterisations/Par02

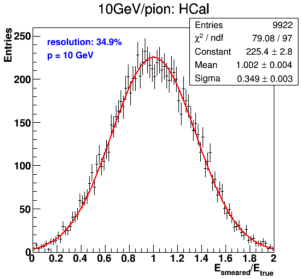
- Simple parametrisation
- Smearing of the momentum in the tracker and energy in the calorimeter
- User input: detector resolution;

$$\sigma_{p_T} = 1.3\%$$

$$\sigma_E = \frac{110\%}{\sqrt{E}} \oplus 9\%$$







Example 1: detector construction

- from GDML;
- explore auxiliary information field to create regions

Example 1: detector construction

- from GDML;
- explore auxiliary information field to create regions

Par02FullDetector.gdml

```
<volume name="TrackerBarrelLog">
  <materialref ref="Beryllium0x7ff5f9e3baf0"/>
  <solidref ref="TrackerBarrel"/>
  <auxiliary auxtype="FastSimModel"
  ↪   auxvalue="TrackerBarrel"/>
</volume>
```

Example 1: detector construction

- from GDML;
- explore auxiliary information field to create regions

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<volume name="TrackerBarrelLog">
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  <auxiliary auxtype="FastSimModel"
  ↪   auxvalue="TrackerBarrel"/>
</volume>
```

Par02DetectorConstruction.cc

```
G4VPhysicalVolume* Par02DetectorConstruction::Construct() {
  G4GDMLParser parser;
  parser.Read( "Par02FullDetector.gdml" );
  const G4GDMLAuxMapType* aAuxMap = parser.GetAuxMap();
  for ( G4GDMLAuxMapType::const_iterator iter = aAuxMap->begin(); iter != aAuxMap->end(); ++iter ) {
    for ( G4GDMLAuxListType::const_iterator vit = (*iter).second.begin(); vit !=
    ↪   (*iter).second.end(); ++vit ) {
      if ( (*vit).type == "FastSimModel" ) {
        G4LogicalVolume* myvol = (*iter).first;
        if ( ( myvol->GetName() ).find( "Tracker" ) != std::string::npos ) {
          fTrackerList.push_back( new G4Region( myvol->GetName() ) );
          fTrackerList.back()->AddRootLogicalVolume( myvol );
        } else [...]
      }
    }
  } ...
}
```

Example 1: detector construction

examples/extended/parameterisations/Par02

- from GDML;
- explore auxiliary information field to create regions

Par02FullDetector.gdml

```
<volume name="TrackerBarrelLog">
  <materialref ref="Beryllium0x7ff5f9e3baf0"/>
  <solidref ref="TrackerBarrel"/>
  <auxiliary auxtype="FastSimModel"
  ↪   auxvalue="TrackerBarrel"/>
</volume>
```

Par02DetectorConstruction.cc

```
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          fTrackerList.push_back( new G4Region( myvol->GetName() ) );
          fTrackerList.back()->AddRootLogicalVolume( myvol );
        } else [...]
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  } ...
}
```

Example 1: detector construction

examples/extended/parameterisations/Par02

- from GDML;
- explore auxiliary information field to create regions

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```
<volume name="TrackerBarrelLog">
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G4VPhysicalVolume* Par02DetectorConstruction::Construct() {
  G4GDMLParser parser;
  parser.Read( "Par02FullDetector.gdml" );
  const G4GDMLAuxMapType* aAuxMap = parser.GetAuxMap();
  for ( G4GDMLAuxMapType::const_iterator iter = aAuxMap->begin(); iter != aAuxMap->end(); ++iter ) {
    for ( G4GDMLAuxListType::const_iterator vit = (*iter).second.begin(); vit !=
    ↪   (*iter).second.end(); ++vit ) {
      if ( (*vit).type == "FastSimModel" ) {
        G4LogicalVolume* myvol = (*iter).first;
        if ( ( myvol->GetName() ).find( "Tracker" ) != std::string::npos ) {
          fTrackerList.push_back( new G4Region( myvol->GetName() ) );
          fTrackerList.back()->AddRootLogicalVolume( myvol );
        } else [...]
      }
    }
  } ...
}
```

Example 1: detector construction

- from GDML;
- explore auxiliary information field to create regions

Par02FullDetector.gdml

```
<volume name="TrackerBarrelLog">
  <materialref ref="Beryllium0x7ff5f9e3baf0"/>
  <solidref ref="TrackerBarrel"/>
  <auxiliary auxtype="FastSimModel"
  ↪   auxvalue="TrackerBarrel"/>
</volume>
```

Par02DetectorConstruction.cc

```
G4VPhysicalVolume* Par02DetectorConstruction::Construct() {
  G4GDMLParser parser;
  parser.Read( "Par02FullDetector.gdml" );
  const G4GDMLAuxMapType* aAuxMap = parser.GetAuxMap();
  for ( G4GDMLAuxMapType::const_iterator iter = aAuxMap->begin(); iter != aAuxMap->end(); ++iter ) {
    for ( G4GDMLAuxListType::const_iterator vit = (*iter).second.begin(); vit !=
    ↪   (*iter).second.end(); ++vit ) {
      if ( (*vit).type == "FastSimModel" ) {
        G4LogicalVolume* myvol = (*iter).first;
        if ( ( myvol->GetName() ).find( "Tracker" ) != std::string::npos ) {
          fTrackerList.push_back( new G4Region( myvol->GetName() ) );
          fTrackerList.back()->AddRootLogicalVolume( myvol );
        } else [...]
      }
    }
  } ...
}
```

Example 1: detector construction

GEANT4 A SIMULATION TOOLKIT

- from GDML;
- explore auxiliary information field to create regions and fast simulation models

Par02FullDetector.gdml

```
<volume name="TrackerBarrelLog">
  <materialref ref="Beryllium0x7ff5f9e3baf0"/>
  <solidref ref="TrackerBarrel"/>
  <auxiliary auxtype="FastSimModel"
   ↪   auxvalue="TrackerBarrel"/>
</volume>
```

Par02DetectorConstruction.cc

```
void Par02DetectorConstruction::ConstructSDandField() {
  for ( G4int iterTracker = 0; iterTracker < G4int(
  ↪   fTrackerList.size() ); iterTracker++ ) {
    // Bound the fast simulation model for the tracker subdetector
    // to all the corresponding Geant4 regions
    Par02FastSimModelTracker* fastSimModelTracker
    = new Par02FastSimModelTracker( "fastSimModelTracker",
    ↪   fTrackerList[ iterTracker ],
    ↪   Par02DetectorParametrisation::eCMS );
    // Register the fast simulation model for deleting
    G4AutoDelete::Register(fastSimModelTracker);
  }...
}
```

Example 1: detector construction

- from GDML;
- explore auxiliary information field to create regions and fast simulation models

Par02FullDetector.gdml

```xml
<volume name="TrackerBarrelLog">
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  <auxiliary auxtype="FastSimModel"
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</volume>
```

Par02DetectorConstruction.cc

```cpp
void Par02DetectorConstruction::ConstructSDandField() {
  for ( G4int iterTracker = 0; iterTracker < G4int(
  ↪   fTrackerList.size() ); iterTracker++ ) {
    // Bound the fast simulation model for the tracker subdetector
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    Par02FastSimModelTracker* fastSimModelTracker
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    ↪   fTrackerList[ iterTracker ],
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    G4AutoDelete::Register(fastSimModelTracker);
  }...
}
```

Example 1: physics list

- register by-hand G4FastSimulationManagerProcess (works also for versions < 10.3)
- process registered for all constructed particles

Par02PhysicsList.cc

```
void Par02PhysicsList::AddParameterisation() {
  G4FastSimulationManagerProcess* fastSimProcess =
    new G4FastSimulationManagerProcess( "G4FSMP" );
  // Registers the fastSimProcess with all the particles as a discrete and
  // continuous process (this works in all cases; in the case that
  ↪  parallel
  // geometries are not used, as in this example, it would be enough to
  // add it as a discrete process).
  auto particleIterator=GetParticleIterator();
  particleIterator->reset();
  while ( (*particleIterator)() ) {
    G4ParticleDefinition* particle = particleIterator->value();
    G4ProcessManager* pmanager = particle->GetProcessManager();
    //pmanager->AddDiscreteProcess( fastSimProcess );    // No parallel
    ↪  geometry
    pmanager->AddProcess( fastSimProcess, -1, 0, 0 );  // General
  }
}
```

Example 1: physics list

- register by-hand G4FastSimulationManagerProcess (works also for versions < 10.3)
- process registered for all constructed particles

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  // continuous process (this works in all cases; in the case that
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  auto particleIterator=GetParticleIterator();
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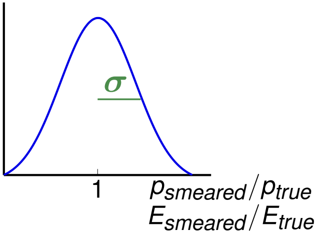
    //pmanager->AddDiscreteProcess( fastSimProcess );    // No parallel
    ↪  geometry
    pmanager->AddProcess( fastSimProcess, -1, 0, 0 );  // General
  }
}
```

Example 1: models

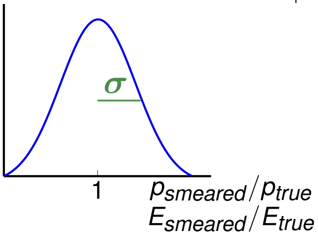
- smearing of momentum (tracker) / energy (calorimeters) with Gaussian;



Example 1: models

- smearing of momentum (tracker) / energy (calorimeters) with Gaussian;
- resolution defined arbitrarily in Par02DetectorParametrisation ([E] = GeV)

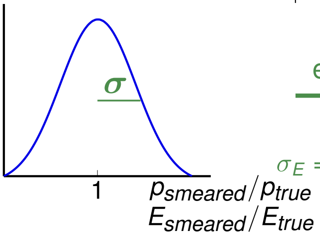
	CMS-like	ALEPH-like	ATLAS-like
σ (Tracker)	1.3%	1%	1%
σ (EMCAL)	$\frac{3\%}{\sqrt{E}} \oplus \frac{12\%}{E} \oplus 0.3\%$	$\frac{18\%}{\sqrt{E}} \oplus 0.9\%$	$\frac{10\%}{\sqrt{E}} \oplus 0.17\%$
σ (HCAL)	$\frac{110\%}{\sqrt{E}} \oplus 9\%$	$\frac{85\%}{\sqrt{E}}$	$\frac{55\%}{\sqrt{E}} \oplus 6\%$



Example 1: models

- smearing of momentum (tracker) / energy (calorimeters) with Gaussian;
- resolution defined arbitrarily in Par02DetectorParametrisation ([E] = GeV)

	CMS-like	ALEPH-like	ATLAS-like
σ (Tracker)	1.3%	1%	1%
σ (EMCAL)	$\frac{3\%}{\sqrt{E}} \oplus \frac{12\%}{E} \oplus 0.3\%$	$\frac{18\%}{\sqrt{E}} \oplus 0.9\%$	$\frac{10\%}{\sqrt{E}} \oplus 0.17\%$
σ (HCAL)	$\frac{110\%}{\sqrt{E}} \oplus 9\%$	$\frac{85\%}{\sqrt{E}}$	$\frac{55\%}{\sqrt{E}} \oplus 6\%$



e.g. 10 GeV π^- →

$\sigma_p = 1.3\%$

$\sigma_E = \frac{110\%}{\sqrt{E}} \oplus 9\% \approx 35\%$

Example 1: models

- smearing of momentum (tracker) / energy (calorimeters) with Gaussian;
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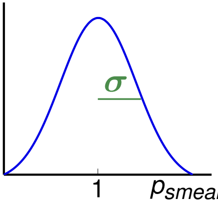

$p_{smeared}/p_{true}$

$E_{smeared}/E_{true}$

e.g. 10 GeV π^-

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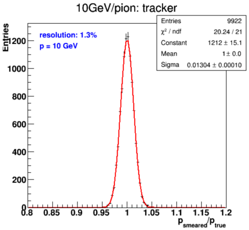

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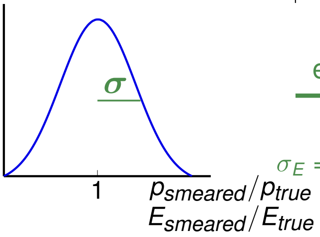

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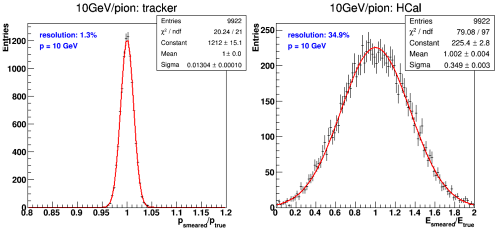

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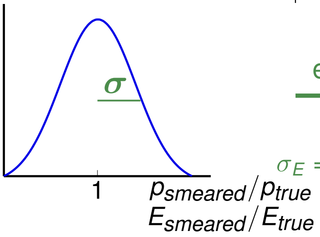

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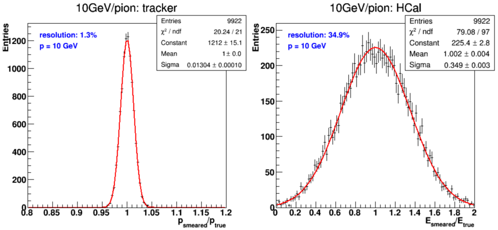

Example 1: models

`examples/extended/parameterisations/Par02`

- smearing of momentum (tracker) / energy (calorimeters) with Gaussian;
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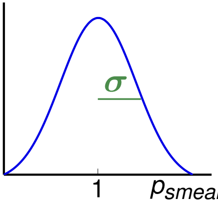

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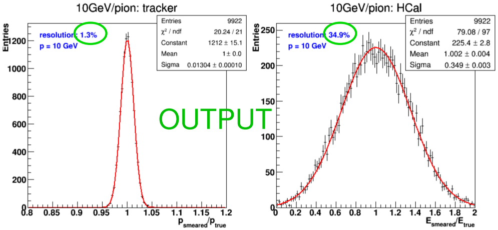
INPUT



Example 1: models

- Tracker: transport it in EM field to the exit-from-envelope, smear momentum;

Par02FastSimModelTracker.cc

```
void Par02FastSimModelTracker::DoIt( const G4FastTrack& aFastTrack, G4FastStep& aFastStep ) {
  G4Track track = * aFastTrack.GetPrimaryTrack();
  ...
  G4PathFinder* fPathFinder = G4PathFinder::GetInstance();
  fPathFinder->ComputeStep( ... );
  aFastStep.ProposePrimaryTrackFinalPosition( endTrack.GetPosition() );
}
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- Calorimeters: particles deposit all energy and are killed (e/γ in EMCal, hadrons in HCal);

Par02FastSimModelEMCal.cc

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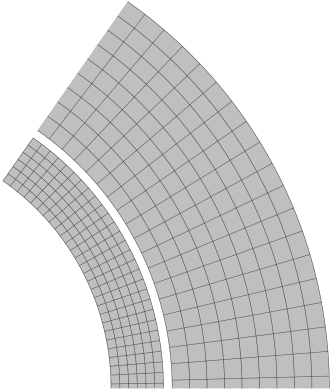
Example 2:

`examples/extended/parameterisations/Par02`

Example 2

Time consuming simulation of calorimeters replaced by creation of energy deposits.



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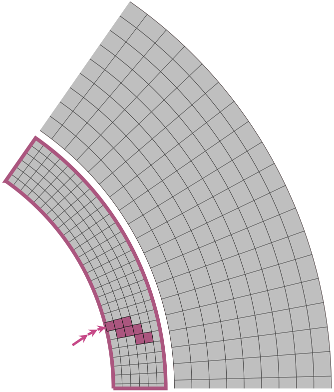

Par01EMShowerModel.cc

- electrons and photons
- electromagnetic calorimeter, envelope in mass geometry

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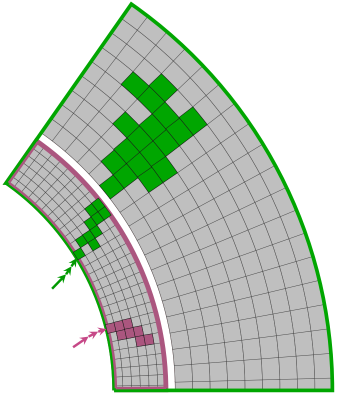

`Par01EMShowerModel.cc`

- electrons and photons
- electromagnetic calorimeter, envelope in mass geometry

`Par01PionShowerModel.cc`

- pions
- both calorimeters: envelope around EMCal and HCal ⇒ parallel geometry

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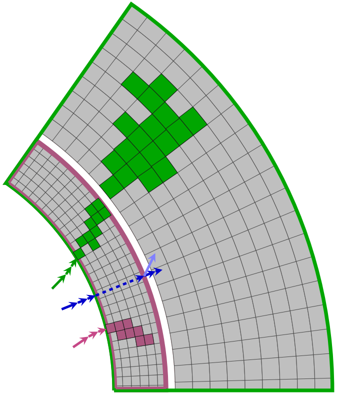

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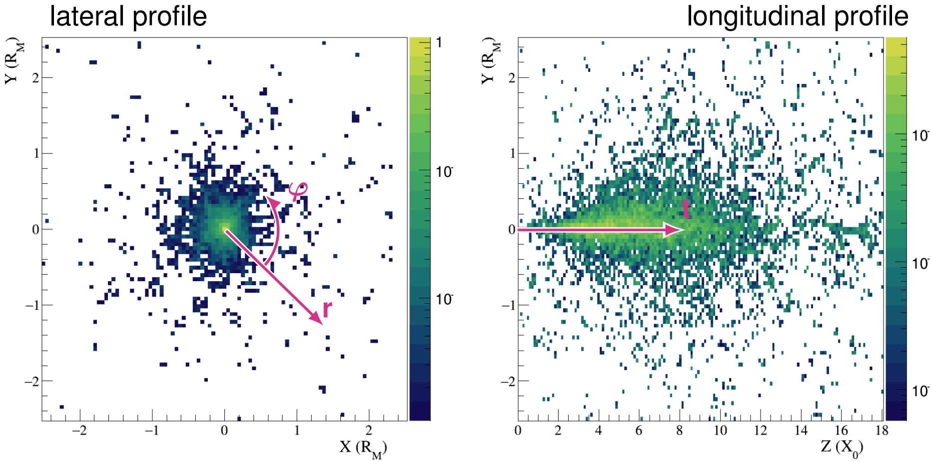
`Par01PiModel.cc`

- create secondaries

Shower profiles



Example 2 – models

How to deposit energy E of electrons/photons? Par01EMShowerModel.cc

Example 2 – models

How to deposit energy E of electrons/photons? `Par01EMShowerModel.cc`

$$f(t, r, \varphi) = f(t)f(r)f(\varphi)$$

1. longitudinal shower profile $f(t)$
2. lateral profile $f(r)$
3. flat azimuthal angle distribution $f(\varphi)$

Example 2 – models

How to deposit energy E of electrons/photons?

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$$f(\varphi) = \frac{1}{2\pi}$$

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$$f(\varphi) = \frac{1}{2\pi}, \qquad f(t; k, \theta) = \frac{x^{k-1} e^{-\frac{x}{\theta}}}{\theta^k \Gamma(k)}$$

Example 2 – models

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4. deposit energy $\Delta E = \frac{E}{N}$ in $N = 100$ points

Example 2 – models

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   - pick t, r and φ from $f(t)$, $f(r)$, and $f(\varphi)$

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4. deposit energy $\Delta E = \frac{E}{N}$ in $N = 100$ points
   - pick t, r and φ from $f(t)$, $f(r)$, and $f(\varphi)$

   in (t,r,φ) inside electromagnetic calorimeter

Example 2 – models

Par01EMShowerModel.cc

```
void Par01EMShowerModel::DoIt(const G4FastTrack& fastTrack, G4FastStep& fastStep) {
  ...
  BuildDetectorResponse();
}
```

Example 2 – models

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void Par01EMShowerModel::DoIt(const G4FastTrack& fastTrack, G4FastStep& fastStep) {
  ...
  BuildDetectorResponse();
}
```

```
void Par01EMShowerModel::BuildDetectorResponse() {
  for (size_t i = 0; i < feSpotList.size(); i++) {
    AssignSpotAndCallHit(feSpotList[i]);
  }
}
```

Example 2 – models

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  ...
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    AssignSpotAndCallHit(feSpotList[i]);
  }
}
```

```
void Par01EMShowerModel::AssignSpotAndCallHit(const Par01EnergySpot &eSpot)
{
  FillFakeStep(eSpot);
  G4VPhysicalVolume* pCurrentVolume = fFakeStep->GetPreStepPoint()->GetPhysicalVolume();
  G4VSensitiveDetector* pSensitive;
  if( pCurrentVolume != 0 ) {
    pSensitive = pCurrentVolume->GetLogicalVolume()->GetSensitiveDetector();
    if( pSensitive != 0 ) {
      pSensitive->Hit(fFakeStep);
    }
  }
}
```

Example 2 – models

How to deposit energy E of pions?

Par01PionShowerModel.cc

Example 2 – models

How to deposit energy E of pions? Par01PionShowerModel.cc

$$f(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$$

1. longitudinal shower profile $f(t, 0, 20\text{cm})$
2. lateral profile $f(r, 0, 10\text{cm})$

Example 2 – models

How to deposit energy E of pions?

Par01PionShowerModel.cc

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$$f(\varphi) = \frac{1}{2\pi}$$

Example 2 – models

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Example 2 – models

GEANT4 A SIMULATION TOOLKIT

How to deposit energy E of pions?

Par01PionShowerModel.cc

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4. deposit energy $\Delta E = \frac{E}{N}$ in $N = 50$ points
   - pick t, r and φ from $f(t)$, $f(r)$, and $f(\varphi)$

Example 2 – models

How to deposit energy E of pions? `Par01PionShowerModel.cc`

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3. azimuthal angle
$$f(\varphi) = \frac{1}{2\pi}$$
4. deposit energy $\Delta E = \frac{E}{N}$ in $N = 50$ points
   - pick t, r and φ from $f(t)$, $f(r)$, and $f(\varphi)$

   in (t,r,φ) inside electromagnetic + hadronic calorimeter envelope

Example 2 – models

How to create secondaries?

Par01PiModel.cc

Par01PiModel.cc

```
// -- First, user has to say how many secondaries will be created:
fastStep.SetNumberOfSecondaryTracks(1);
G4ParticleMomentum direction(fastTrack.GetPrimaryTrackLocalDirection());
direction.setZ(direction.z()*0.5);
direction.setY(direction.y()+direction.z()*0.1);
direction = direction.unit(); // necessary ?
// -- dynamics (Note that many constructors exists for G4DynamicParticle
G4DynamicParticle dynamique(G4Gamma::GammaDefinition(),
                            direction,
                            fastTrack.GetPrimaryTrack()->
                            GetKineticEnergy()/2.);
G4double Dist;
Dist = fastTrack.GetEnvelopeSolid()->
DistanceToOut(fastTrack.GetPrimaryTrackLocalPosition(),
              direction);
G4ThreeVector posi;
posi = fastTrack.GetPrimaryTrackLocalPosition() + Dist*direction;
fastStep.CreateSecondaryTrack(dynamique, posi,
                              fastTrack.GetPrimaryTrack()->GetGlobalTime());
```

Example 2 – models

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posi = fastTrack.GetPrimaryTrackLocalPosition() + Dist*direction;
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Example 2 – models

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                            GetKineticEnergy()/2.);
G4double Dist;
Dist = fastTrack.GetEnvelopeSolid()->
DistanceToOut(fastTrack.GetPrimaryTrackLocalPosition(),
              direction);
G4ThreeVector posi;
posi = fastTrack.GetPrimaryTrackLocalPosition() + Dist*direction;
fastStep.CreateSecondaryTrack(dynamique, posi,
                              fastTrack.GetPrimaryTrack()->GetGlobalTime());
```

Example 2 – models

How to create secondaries?

Par01PiModel.cc

Par01PiModel.cc

```
// -- First, user has to say how many secondaries will be created:
fastStep.SetNumberOfSecondaryTracks(1);
G4ParticleMomentum direction(fastTrack.GetPrimaryTrackLocalDirection());
direction.setZ(direction.z()*0.5);
direction.setY(direction.y()+direction.z()*0.1);
direction = direction.unit(); // necessary ?
// -- dynamics (Note that many constructors exists for G4DynamicParticle
G4DynamicParticle dynamique(G4Gamma::GammaDefinition(),
                            direction,
                            fastTrack.GetPrimaryTrack()->
                            GetKineticEnergy()/2.);
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Example 2 – models

How to transport particles to the outer boundary?

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G4ThreeVector position;
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distance = fastTrack.GetEnvelopeSolid()->
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position = fastTrack.GetPrimaryTrackLocalPosition() +
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// -- set final position:
fastStep.ProposePrimaryTrackFinalPosition(position);
```

Example 2 – models

How to transport particles to the outer boundary? Par01PiModel.cc

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Example 3:

examples/extended/parameterisations/gflash

Example 3

- the only implementation of G4VFastSimulationModel in Geant4 (outside `examples/`)
- `arXiv:hep-ex/0001020`
- physics reference manual, chapter 18

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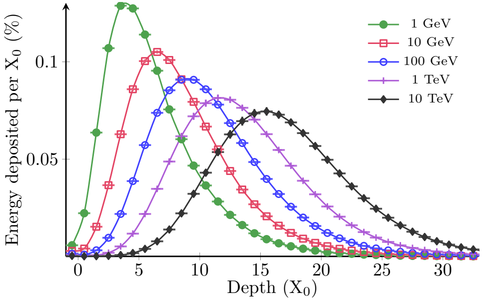
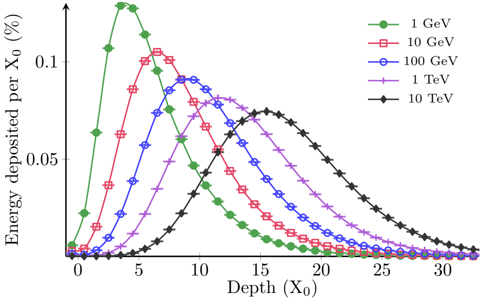
- flat distribution in azimuthal angle $f(\varphi) = \frac{1}{2\pi}$
- $f(t)$ and $f(r)$ parametrised as a function of particle's energy (E) and medium (Z)
- t and r are expressed in units of X_0 and R_M

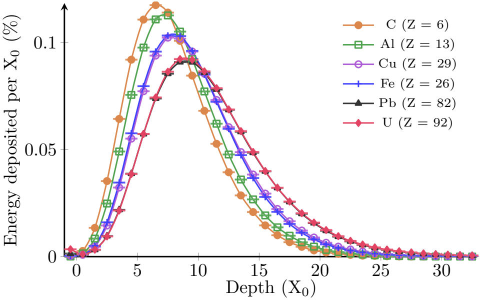
Example 3 - longitudinal profile



$$T \sim \ln E$$

Example 3 - longitudinal profile





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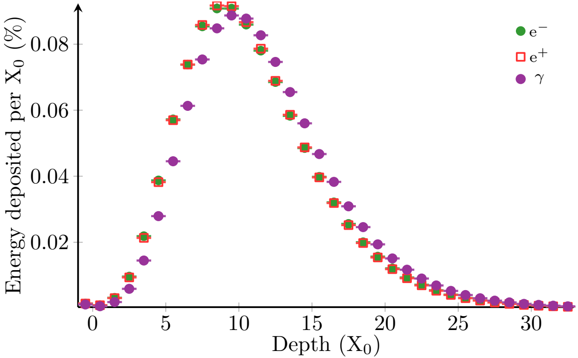

Example 3 - longitudinal profile

$$f(t) = \left\langle \frac{1}{E} \frac{dE(t)}{dt} \right\rangle = \frac{(\beta t)^{\alpha-1} \beta e^{-\beta t}}{\Gamma(\alpha)}$$

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- shower maximum $T = \frac{\alpha-1}{\beta}$
- Description dependent on $y = \frac{E}{E_c}$:

$$T = \ln y + l_1$$
$$\alpha = l_2 + (l_3 + \frac{l_4}{Z}) \ln y$$

Example 3 - longitudinal profile

GEANT4 A SIMULATION TOOLKIT

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- shower maximum $T = \frac{\alpha - 1}{\beta}$
- Description dependent on $y = \frac{E}{E_c}$:

$$T = \ln y + I_1$$
$$\alpha = I_2 + (I_3 + \frac{I_4}{Z}) \ln y$$

A.1 Homogeneous Media

A.1.1 Average longitudinal profiles

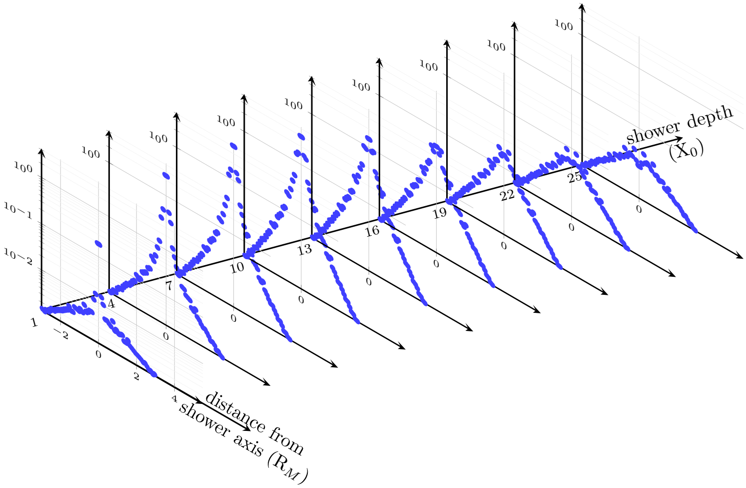
$$T_{hom} = \ln y - 0.858$$
$$\alpha_{hom} = 0.21 + (0.492 + 2.38/Z) \ln y$$

A.1.2 Fluctuated longitudinal profiles

$$\langle \ln T_{hom} \rangle = \ln(\ln y - 0.812)$$
$$\sigma(\ln T_{hom}) = (-1.4 + 1.26 \ln y)^{-1}$$
$$\langle \ln \alpha_{hom} \rangle = \ln(0.81 + (0.458 + 2.26/Z) \ln y)$$
$$\sigma(\ln \alpha_{hom}) = (-0.58 + 0.86 \ln y)^{-1}$$
$$\rho(\ln T_{hom}, \ln \alpha_{hom}) = 0.705 - 0.023 \ln y$$

arXiv:hep-ex/0001020

Example 3 – lateral profile



Example 3 – lateral profile

$$f(r) = \left\langle \frac{1}{dE(t)} \frac{dE(t,r)}{dr} \right\rangle$$

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Example 3 – lateral profile

$$f(r) = \left\langle \frac{1}{dE(t)} \frac{dE(t,r)}{dr} \right\rangle = p f_{\mathrm{core}}(r) + (1-p) f_{\mathrm{tail}}(r) =$$

$$= p \frac{2rR^2_{\mathrm{core}}}{\left(r^2 + R^2_{\mathrm{core}}\right)^2} + (1-p) \frac{2rR^2_{\mathrm{tail}}}{\left(r^2 + R^2_{\mathrm{tail}}\right)^2}$$

Example 3 – lateral profile

$$f(r) = \left\langle \frac{1}{dE(t)} \frac{dE(t,r)}{dr} \right\rangle = pf_{\mathrm{core}}(r) + (1-p) f_{\mathrm{tail}}(r) =$$

$$= p \frac{2rR^2_{\mathrm{core}}}{\left(r^2 + R^2_{\mathrm{core}}\right)^2} + (1-p) \frac{2rR^2_{\mathrm{tail}}}{\left(r^2 + R^2_{\mathrm{tail}}\right)^2}$$

Description dependent on $\tau = \frac{t}{T}$:

$$R_{\mathrm{core}}(\tau) = r_1 + r_2 \tau$$

$$R_{\mathrm{tail}}(\tau) = r_3 \left(\mathrm{e}^{r_4(\tau - r_5)} + \mathrm{e}^{r_6(\tau - r_7)} \right)$$

$$p(\tau) = r_8 \exp\left(\frac{r_9 - \tau}{r_{10}} - \exp\left(\frac{r_9 - \tau}{r_{10}} \right) \right)$$

Example 3 – lateral profile

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A.1.3 Average radial profiles

$$R_{C,hom}(\tau) = z_1 + z_2\tau$$
$$R_{T,hom}(\tau) = k_1\{\exp(k_3(\tau - k_2)) + \exp(k_4(\tau - k_2))\}$$
$$p_{hom}(\tau) = p_1 \exp\left\{ \frac{p_2 - \tau}{p_3} - \exp\left(\frac{p_2 - \tau}{p_3} \right) \right\}$$

with

$$z_1 = 0.0251 + 0.00319 \ln E$$
$$z_2 = 0.1162 + -0.000381 Z$$
$$k_1 = 0.659 + -0.00309 Z$$
$$k_2 = 0.645$$
$$k_3 = -2.59$$
$$k_4 = 0.3585 + 0.0421 \ln E$$
$$p_1 = 2.632 + -0.00094 Z$$
$$p_2 = 0.401 + 0.00187 Z$$
$$p_3 = 1.313 + -0.0686 \ln E$$

A.1.4 Fluctuated radial profiles

$$\tau_i = \frac{t}{\langle t \rangle_i} \frac{\exp(\langle \ln \alpha \rangle)}{\exp(\langle \ln \alpha \rangle) - 1}$$
$$N_{Spot} = 93 \ln(Z) E^{0.876}$$
$$T_{Spot} = T_{hom}(0.698 + 0.00212 Z)$$
$$\alpha_{Spot} = \alpha_{hom}(0.639 + 0.00334 Z)$$

arXiv:hep-ex/0001020

Example 3 – model

ExGflashDetectorConstruction.cc

```
void ExGflashDetectorConstruction::ConstructSDandField()
{
  // -- sensitive detectors:
  G4SDManager* SDman = G4SDManager::GetSDMpointer();
  ExGflashSensitiveDetector* CaloSD
  = new ExGflashSensitiveDetector("Calorimeter",this);
  SDman->AddNewDetector(CaloSD);
  fCrystal_log->SetSensitiveDetector(CaloSD);

  // Get nist material manager
  G4NistManager* nistManager = G4NistManager::Instance();
  G4Material*          pbWO4 = nistManager->FindOrBuildMaterial("G4_PbWO4");
  // -- fast simulation models:
  // **********************************************
  // * Initializing shower modell
  // ***********************************************
  G4cout << "Creating shower parameterization models" << G4endl;
  fFastShowerModel = new GFlashShowerModel("fFastShowerModel", fRegion);
  fParameterisation = new GFlashHomoShowerParameterisation(pbWO4);
  fFastShowerModel->SetParameterisation(*fParameterisation);
  // Energy Cuts to kill particles:
  fParticleBounds = new GFlashParticleBounds();
  fFastShowerModel->SetParticleBounds(*fParticleBounds);
  // Makes the EnergieSpots
  fHitMaker = new GFlashHitMaker();
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Example 3 – model

examples/extended/parameterisations/gflash

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Example 3 – model

ExGflashSensitiveDetector.hh

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class ExGflashSensitiveDetector: public G4VSensitiveDetector,
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          ...
          virtual G4bool ProcessHits(G4Step*,G4TouchableHistory*);
          virtual G4bool ProcessHits(G4GFlashSpot*aSpot,G4TouchableHistory*);
          ...
};
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Sampling calorimeter

GVFlashHomoShowerTuning can be used to used tuned parameters (l_1, l_2, ... , r_1, r_2, ...)

Example 3 – model

ExGflashSensitiveDetector.hh

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                                 public G4VGFlashSensitiveDetector {
             ...
             virtual G4bool ProcessHits(G4Step*,G4TouchableHistory*);
             virtual G4bool ProcessHits(G4GFlashSpot*aSpot,G4TouchableHistory*);
             ...
};
```

Sampling calorimeter

GVFlashHomoShowerTuning can be used to used tuned parameters (l_1, l_2, ... , r_1, r_2, ...)

For simulation in sampling detectors use GFlashSamplingShowerParameterisation and GFlashSamplingShowerTuning

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