Version 11.2

Fast Simulation

Anna Zaborowska

October 16, 2024

Outline

1. What is fast simulation?
2. How to use it in Geant4
   - where
   - what
   - how

   } to parametrise
3. Short summary
4. Examples

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example

link to code in G4 v11.2.p02

```
...
```

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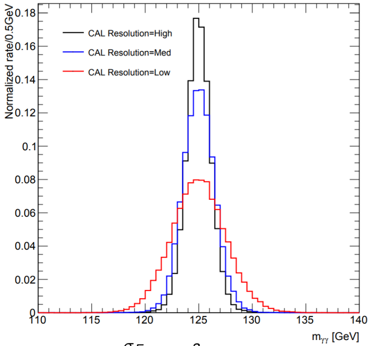
Fast simulation hooks in Geant4 allow to overtake control over particles in certain regions – user decides what happens and when/if they return to the detailed simulation.

Why to use parameterisation / fast(er) simulation?

- Physics studies that assume certain detector performance
  - to speed-up simulation of already known detector (e.g. extracted efficiency/resolution from detailed simulation)

arXiv:1606.09408



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a=20%, *c*=2%

a=10%, *c*=1%

a=6%, *c*=0.7%

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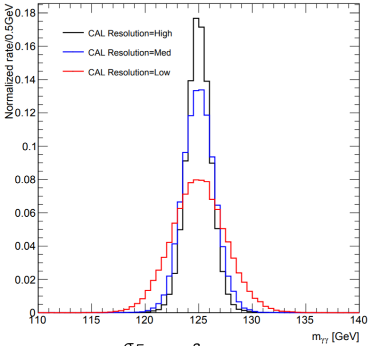

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  - to speed-up simulation of already known detector (e.g. extracted efficiency/resolution from detailed simulation)
  - to study impact of detector performance on physics observables (example in the plot: calorimeter resolution on Higgs mass)
  - to study in detail only one detector, with others parametrised (e.g. parametrised tracker in front of in-detail calorimeter)

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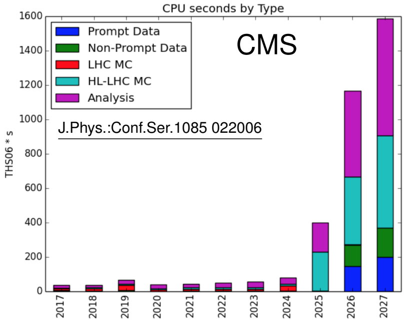
- To speed-up simulation in order to generate more data within same CPU time
  - to match available computing resources;
  - to provide sufficient amount of simulation data for comparison with the experimental data;



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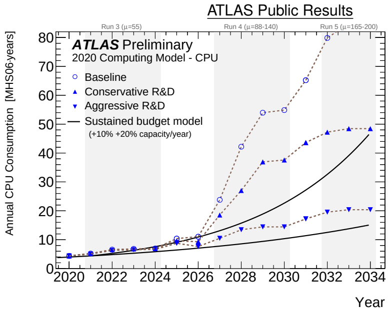

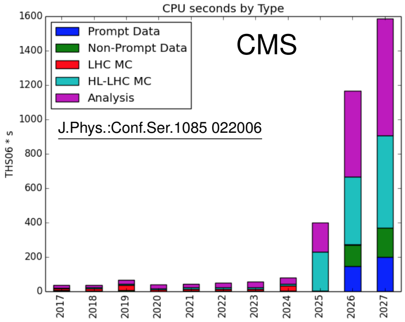

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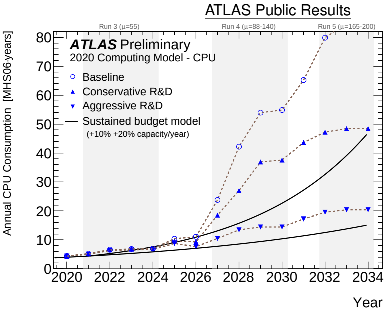

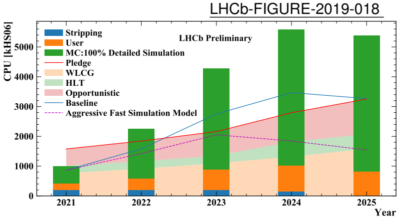

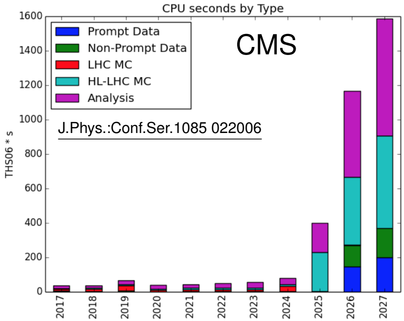

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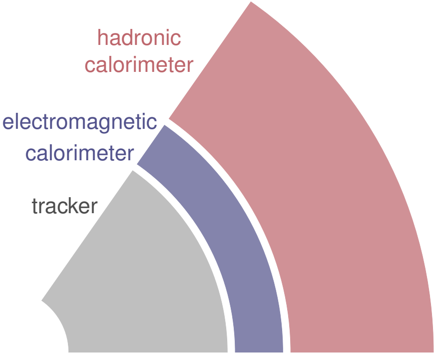

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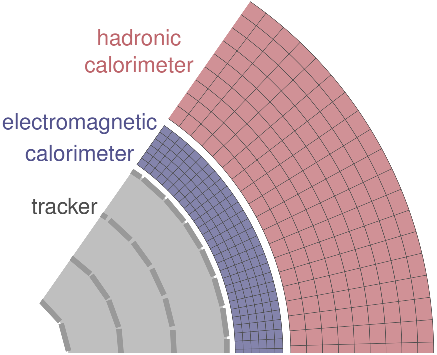

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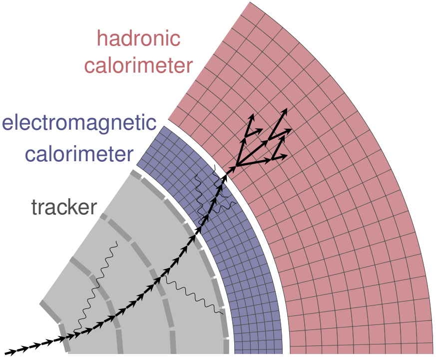

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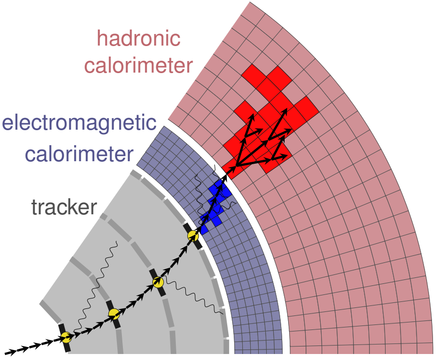

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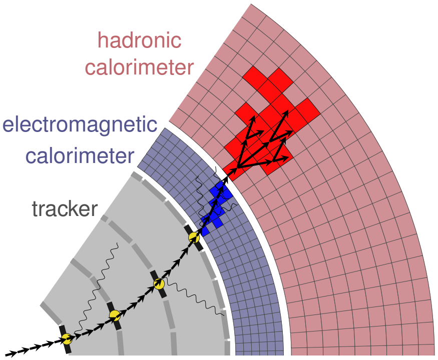

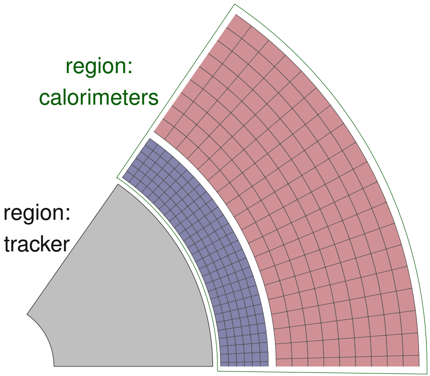

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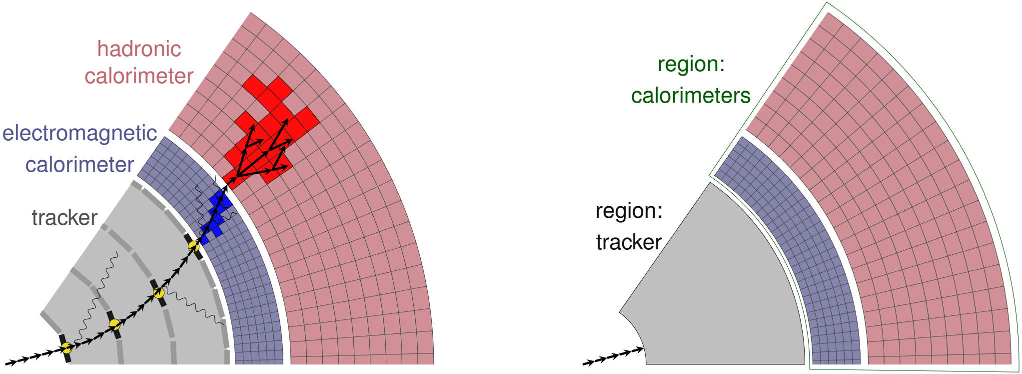

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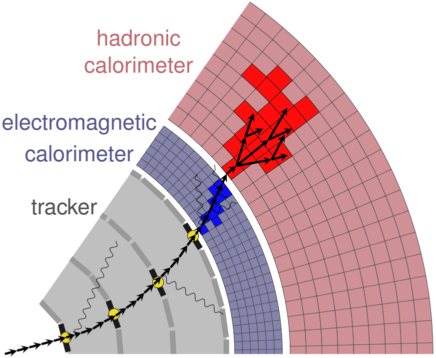

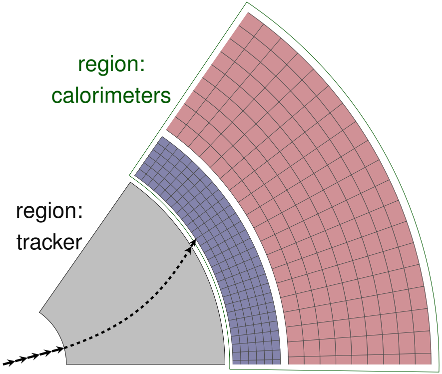

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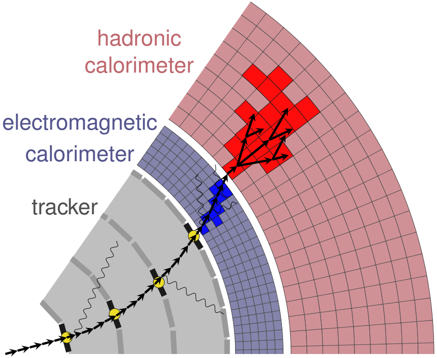
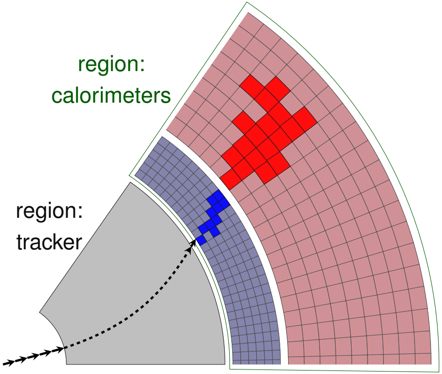
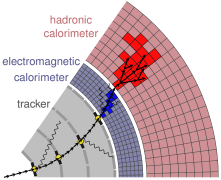




Fast simulation is a shortcut to the standard tracking and detailed simulation.

Simulation of particle passage



detailed / “full” simulation

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

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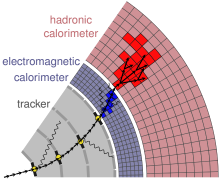
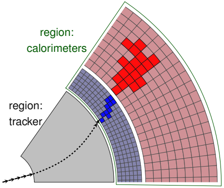


detailed / “full” simulation

parameterisation / “fast” simulation



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- which particles
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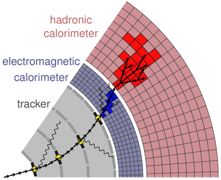

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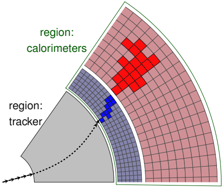

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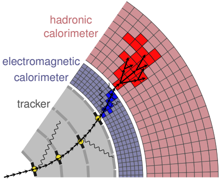

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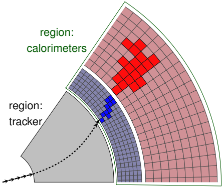

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Defining both ‘full’ and ‘fast’ simulation within one framework (Geant4) offers great flexibility to seamlessly mix both types.

Where?

Parameterisation may be realised within:

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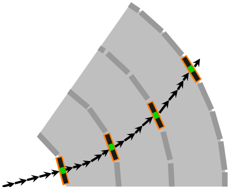
sub-volume

(many volumes)



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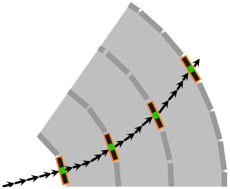
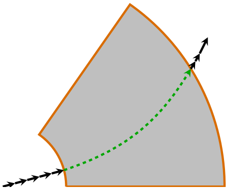


detector envelope (single volume)



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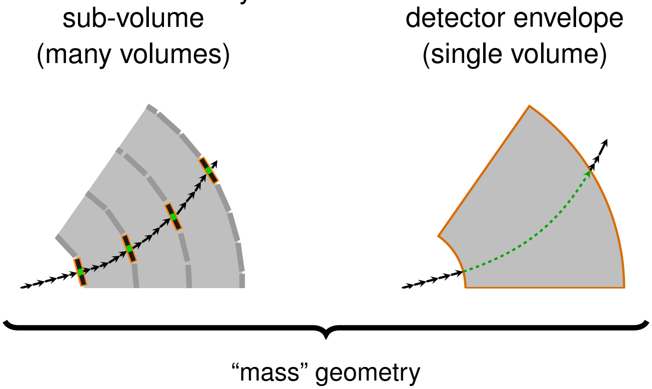

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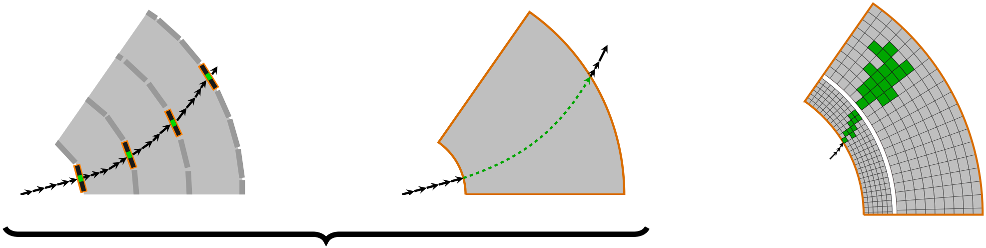
Parameterisation may be realised within:

sub-volume	detector envelope	assembly of volumes
(many volumes)	(single volume)	(non-physical volume)



"mass" geometry

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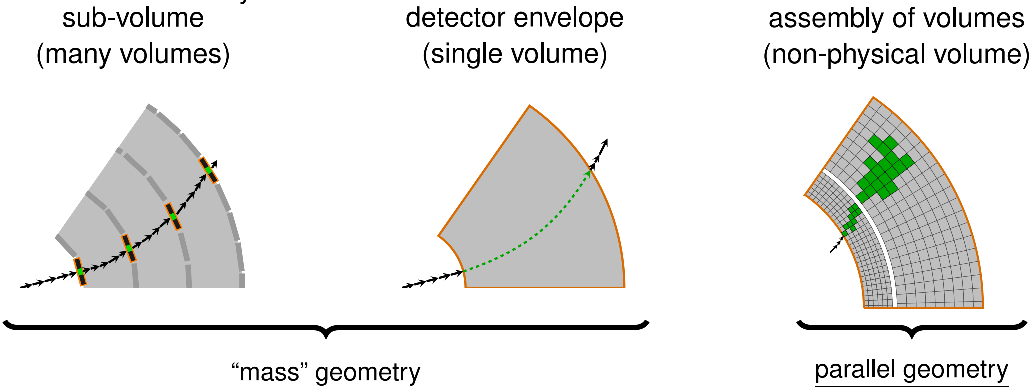

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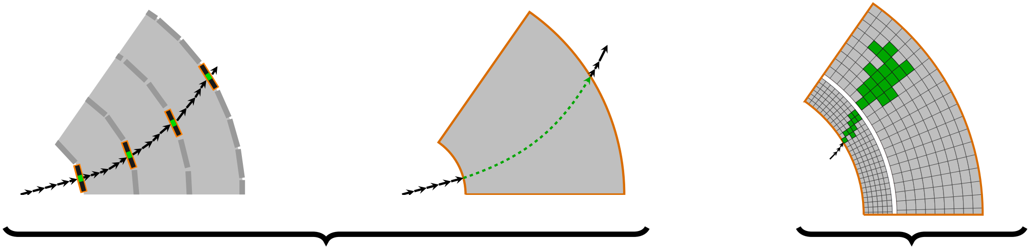

“mass” geometry

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

```
G4Region* caloRegion = new G4Region("EM_calo_region");
caloRegion->AddRootLogicalVolume(calorimeterLog); // calorimeterLog is a G4LogicalVolume
```

for parallel geometry:

examples/extended/parameterisations/Par01/src/Par01ParallelWorldForPion.cc

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  G4Region* ghostRegion = new G4Region("GhostCalorimeterRegion");
// ghostLogical is a G4LogicalVolume in parallel geometry, a box made of air encompassing both EM&H calorimeters
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G4FastSimulationPhysics helps to add parameterisation process on top of any other physics list (which is used where parameterisation is not invoked).

(since v10.3, for older versions consult user's guide or slide 29)

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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- for selected particle types

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- ☐ if trigger is issued

  - check particle type or intrinsic information (from G4ParticleDefinition)
  - check dynamic conditions (from G4FastTrack)
    - energy, momentum, direction, ... (from G4Track)

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    - local coordinates (from G4LogicalVolume)

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  implementation of G4VFastSimulationModel class;

  - check particle type or intrinsic information (from G4ParticleDefinition)
  - check dynamic conditions (from G4FastTrack)
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Parameterisation 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;

- ☑ for selected particle types

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  implementation of G4VFastSimulationModel class;

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    - energy, momentum, direction, ... (from G4Track)
    - local coordinates (from G4LogicalVolume)

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

G4VFastSimulationModel (1/4)

Core of the parameterisation:

- **which** particles
- **how**/what happens

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- **how**/what happens

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

Core of the parameterisation:

- **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 (1/4)

Core of the parameterisation:

- **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);
```

Core of the parameterisation:

- **which** particles
- **how**/what happens

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
```

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

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

Par01EMShowerModel.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
```

Par01EMShowerModel.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 → (G4FastTrack&)

output information: G4FastStep → (G4FastStep&)

How to deposit energy with your model?

since Geant4 v10.7

- Helper classes (`G4FastHit`, `G4FastSimHitMaker`) to deposit energy at given positions (if within the sensitive detector).
- Geant4 will look for a sensitive detector at given position, and if found – deposit energy.

How to deposit energy with your model?

since Geant4 v10.7

- Helper classes (`G4FastHit`, `G4FastSimHitMaker`) to deposit energy at given positions (if within the sensitive detector).
- Geant4 will look for a sensitive detector at given position, and if found – deposit energy.

`G4FastSimHitMaker::make(const G4FastHit& aHit, const G4FastTrack& aTrack)` Par03EMShowerModel.cc

```
void Par03EMShowerModel::DoIt(const G4FastTrack& aFastTrack, G4FastStep& aFastStep)
{
  ...
  G4double energy = aFastTrack.GetPrimaryTrack()->GetKineticEnergy();
  ...
  G4ThreeVector position;
  ...
  G4int generatedHits = 0;
  while(generatedHits < fNbOfHits)
  {
    position = ...
    // Create energy deposit in the detector
    // This will call appropriate sensitive detector class
    fHitMaker->make(G4FastHit(position, energy / fNbOfHits), aFastTrack);
    generatedHits++;
  }
}
```

How to deposit energy with your model?

- Helper classes (`G4FastHit`, `G4FastSimHitMaker`) to deposit energy at given positions (if within the sensitive detector).
- Geant4 will look for a sensitive detector at given position, and if found – deposit energy.

`G4FastSimHitMaker::make(const G4FastHit& aHit, const G4FastTrack& aTrack)` Par03EMShowerModel.cc

```
void Par03EMShowerModel::DoIt(const G4FastTrack& aFastTrack, G4FastStep& aFastStep)
{
  ...
  G4double energy = aFastTrack.GetPrimaryTrack()->GetKineticEnergy();
  ...
  G4ThreeVector position;
  ...
  G4int generatedHits = 0;
  while(generatedHits < fNbOfHits)
  {
    position = ...
    // Create energy deposit in the detector
    // This will call appropriate sensitive detector class
    fHitMaker->make(G4FastHit(position, energy / fNbOfHits), aFastTrack);
    generatedHits++;
  }
}
```

G4VFastSimSensitiveDetector

- `G4VFastSimSensitiveDetector` must me used as base class in addition to inheritance from the usual base class `G4VSensitiveDetector`.
- `ProcessHits(...)` method must be implemented and describe how hits should be saved in the hit collections.

G4VFastSimSensitiveDetector

- `G4VFastSimSensitiveDetector` must me used as base class in addition to inheritance from the usual base class `G4VSensitiveDetector`.
- `ProcessHits(...)` method must be implemented and describe how hits should be saved in the hit collections.

G4VFastSimSensitiveDetector examples/extended/parameterisations/Par03/include/zPar03SensitiveDetector.hh

```
class Par03SensitiveDetector
  : public G4VSensitiveDetector
  , public G4VFastSimSensitiveDetector
{
  ...
  /// Process energy deposit from the full simulation.
  virtual G4bool ProcessHits(G4Step* aStep, G4TouchableHistory* aROhist) final;
  /// Process energy deposit from the fast simulation.
  virtual G4bool ProcessHits(const G4FastHit* aHit, const G4FastTrack* aTrack,
                             G4TouchableHistory* aROhist) final;
  ...
}
```

Summary: fast simulation in Geant4

Step-by-step:

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Step-by-step:

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

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   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**)

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 (recommended: via **G4FastSimulationPhysics**)

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   user's implementation of **G4VFastSimulationModel**
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3. Specify **where** parameterisation takes place

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

1. Implement model that specifies **which** particles, under what conditions and **how** should be parameterised
   user's implementation of **G4VFastSimulationModel**
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   by creating **G4Region**, attaching a root G4LogicalVolume, and passing it to a constructor of implementation of G4VFastSimulationModel

Existing examples: `examples/extended/parameterisations/`

UI commands

```
/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`
- `examples/extended/parameterisations/Par03/src/`
  - `Par03EMShowerModel.cc`
- `examples/extended/parameterisations/Par04/src/`
  - `Par04MLFastSimModel.cc`
- `GFlashShowerModel`

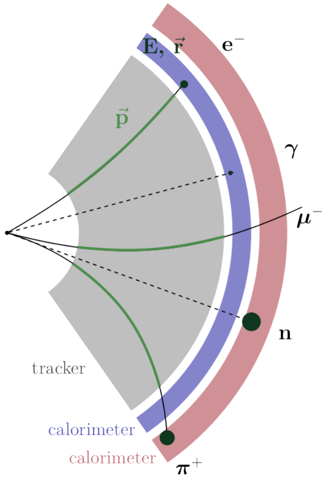
Example 1:

examples/extended/parameterisations/Par02

Example 1

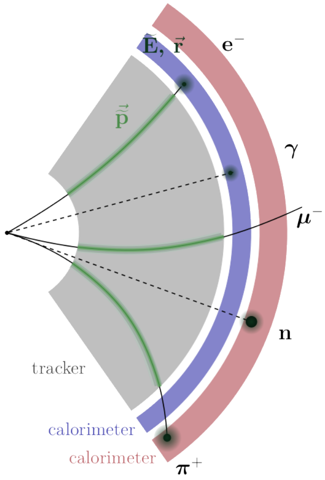
- Simple parameterisation

Example 1



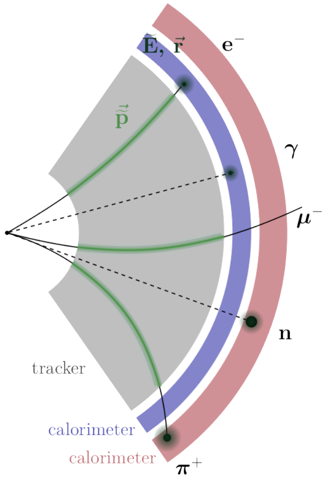
- Simple parameterisation

Example 1



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

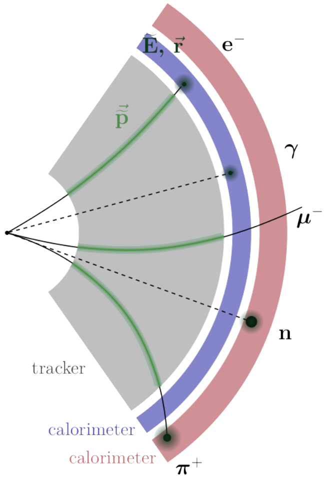
Example 1



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

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

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



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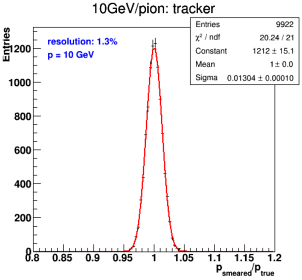

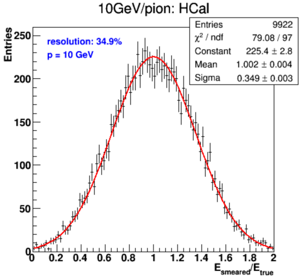

Example 1: detector construction

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

Example 1: detector construction

examples/extended/parameterisations/Par02

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

Par02FullDetector.gdml

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

Example 1: detector construction

- from GDML;
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```
<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

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

```
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

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

```
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 and fast simulation models

Par02FullDetector.gdml

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

examples/extended/parameterisations/Par02

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

Par02FullDetector.gdml

```xml
<volume name="TrackerBarrelLog">
  <materialref ref="Beryllium0x7ff5f9e3baf0"/>
  <solidref ref="TrackerBarrel"/>
  <auxiliary auxtype="FastSimModel" auxvalue="TrackerBarrel"/>
</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
    // 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: physics list

- register by-hand G4FastSimulationManagerProcess
- process registered for all constructed particles

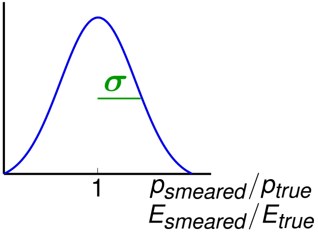
(Not recommended!
But also works for versions < 10.3)

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: models

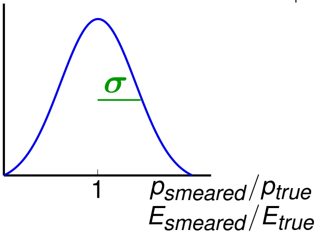
- smearing of momentum (tracker) / energy (calorimeters) with Gaussian;



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)	$\frac{110\%}{\sqrt{E}} \oplus 9\%$	$\frac{85\%}{\sqrt{E}}$	$\frac{55\%}{\sqrt{E}} \oplus 6\%$



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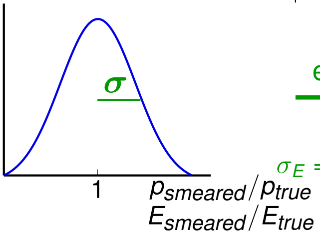

e.g. 10 GeV π^-

$\sigma_p = 1.3\%$

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

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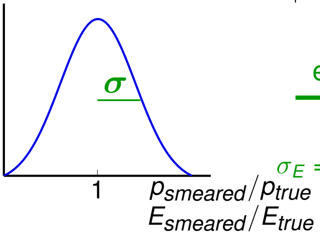

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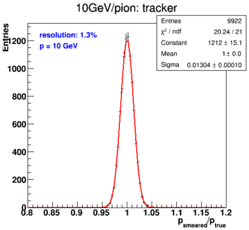

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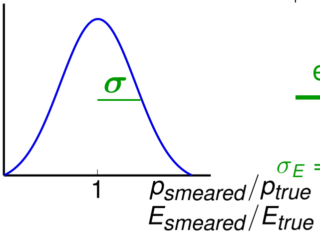

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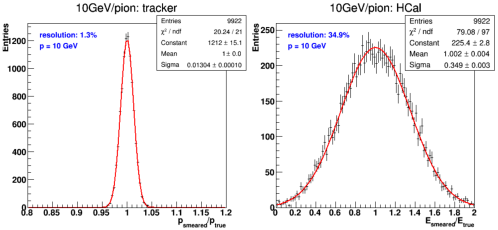

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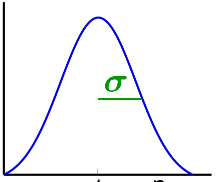

$p_{smeared}/p_{true}$

$E_{smeared}/E_{true}$

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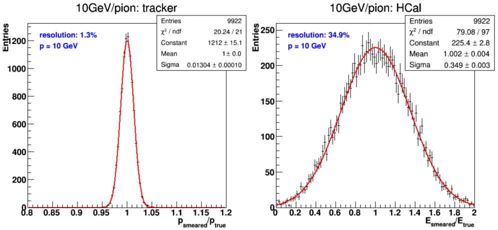

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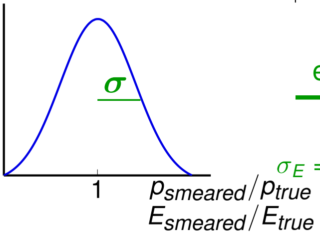

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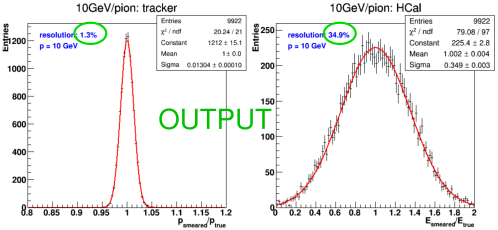

Example 1: models

- 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();
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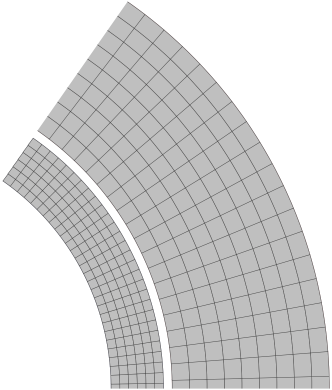
Example 2:

`examples/extended/parameterisations/Par01`

Example 2

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



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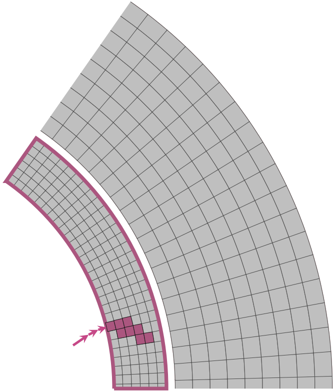

Par01EMShowerModel.cc

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

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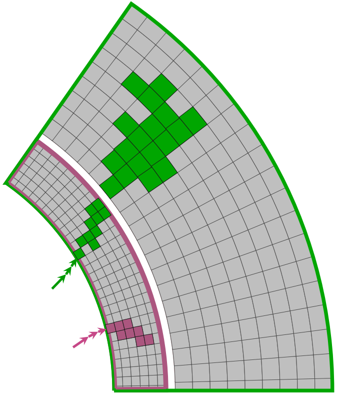

Par01EMShowerModel.cc

- electrons and photons
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Par01PionShowerModel.cc

- pions
- both calorimeters: envelope around EMCal and HCal $\Rightarrow$ parallel geometry

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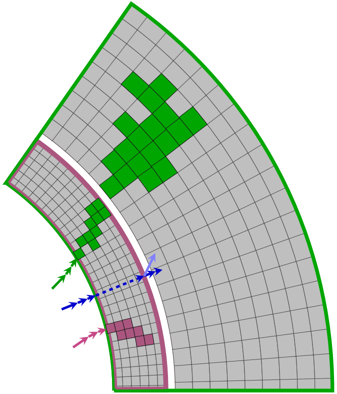


Par01EMShowerModel.cc

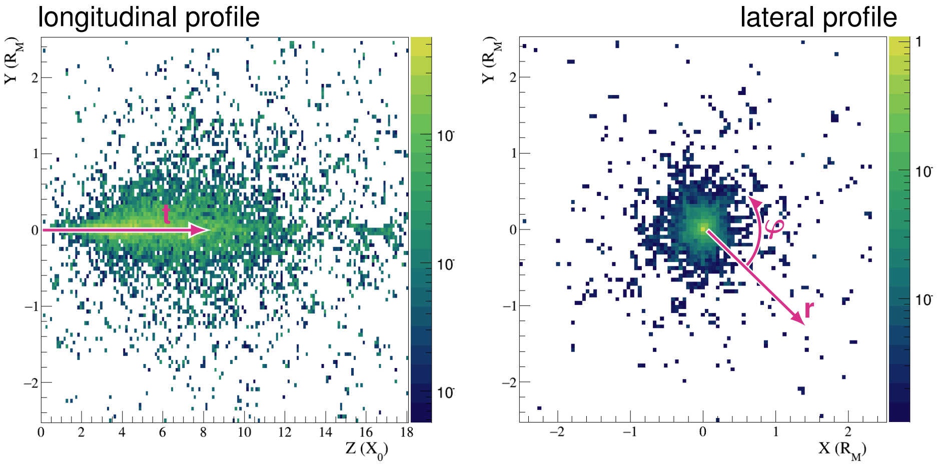
- electrons and photons
- electromagnetic calorimeter, envelope in mass geometry

Par01PionShowerModel.cc

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

Par01PiModel.cc

- create secondaries


longitudinal profile
lateral profile
Y (R$_M$)
Z (X$_0$)
X (R$_M$)
t
r
φ
1
10

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 $f(t)$
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3. flat azimuthal angle distribution $f(\varphi)$

Example 2 – models

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

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

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How to deposit energy E of electrons/photons?

Par01EMShowerModel.cc

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

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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

How to deposit energy E of electrons/photons?

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

1. longitudinal shower profile $f(t)$
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$$f(\varphi) = \frac{1}{2\pi}, \qquad f(t;k,\theta) = \frac{x^{k-1}e^{-\frac{x}{\theta}}}{\theta^k\Gamma(k)}, \qquad f(r) = \begin{cases} \frac{0.9}{2\cdot R_M} & \text{for} \quad |r| \leqslant R_M \\ \frac{0.1}{5\cdot R_M} & \text{for} \quad R_M < |r| \leqslant 3.5\cdot R_M \\ 0 & \text{for} \quad |r| \geqslant 3.5\cdot R_M \end{cases}$$

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

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

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

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

   in (t,r,φ) inside electromagnetic calorimeter

Example 2 – models

Manual placement of hits. Not needed if `G4FastSimHitMaker` is used - see slide 18.

Par01EMShowerModel.cc

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

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Manual placement of hits. Not needed if `G4FastSimHitMaker` is used - see slide 18.

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```
void Par01EMShowerModel::BuildDetectorResponse() {
  for (size_t i = 0; i < feSpotList.size(); i++) {
    AssignSpotAndCallHit(feSpotList[i]);
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```
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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$$f(\varphi) = \frac{1}{2\pi}$$

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Example 2 – models

How to deposit energy E of pions?

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

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

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

How to create secondaries? Par01PiModel.cc

Par01PiModel.cc

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fastStep.CreateSecondaryTrack(dynamique, posi,
                              fastTrack.GetPrimaryTrack()->GetGlobalTime());
```

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

Par01PiModel.cc

```
G4ThreeVector position;
G4double distance;
distance = fastTrack.GetEnvelopeSolid()->
  DistanceToOut(fastTrack.GetPrimaryTrackLocalPosition(),
                fastTrack.GetPrimaryTrackLocalDirection());
position = fastTrack.GetPrimaryTrackLocalPosition() +
  distance*fastTrack.GetPrimaryTrackLocalDirection();

// -- set final position:
fastStep.ProposePrimaryTrackFinalPosition(position);
```

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Par01PiModel.cc

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distance = fastTrack.GetEnvelopeSolid()->
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Example 2 – models

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

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position = fastTrack.GetPrimaryTrackLocalPosition() +
  distance*fastTrack.GetPrimaryTrackLocalDirection();

// -- set final position:
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Example 3:

examples/extended/parameterisations/Par03

Example 3 – EM shower model

Based on PDG (chapter 33.5)

Par03EMShowerModel.cc

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Par03EMShowerModel.cc

Based on PDG (chapter 33.5)

1. longitudinal shower profile

$$\frac{\mathrm{d}E}{\mathrm{d}t} = E_0 b \frac{(bt)^{a-1}\, \mathrm{e}^{-bt}}{\Gamma(a)} \qquad (33.35)$$

Example 3 – EM shower model

Based on PDG (chapter 33.5)

Par03EMShowerModel.cc

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$$\frac{\mathrm{d}E}{\mathrm{d}t} = E_0 b \frac{(bt)^{a-1}\,\mathrm{e}^{-bt}}{\Gamma(a)} \qquad (33.35)$$

$$b = 0.5 \;\; (Fig\ 33.21), \quad \frac{a-1}{b} = ln\frac{E}{E_c} + C_j, \;\; C_j = \begin{cases} +0.5 & \text{for}\gamma \\ -0.5 & \text{for} e^{\pm} \end{cases} \qquad (33.36)$$

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2. Gaussian lateral profile with 90% energy deposited within a cylinder of radius equal to Moliere radius

Example 3 – EM shower model

`examples/extended/parameterisations/Par03`

Based on PDG (chapter 33.5) `Par03EMShowerModel.cc`

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2. Gaussian lateral profile with 90% energy deposited within a cylinder of radius equal to Moliere radius
3. Deposit energy $\Delta E = \frac{E}{N}$ in N (100 by default) points sampling position from Gamma and Gaussian distributions
4. Created hits are deposited in the detector using its readout geometry, using the helper class `G4FastSimHitMaker` that locates the volume, and calls appropriate sensitive detector class.

Example 4:

examples/extended/parameterisations/gflash/gflash1

Example 4 - previous Geant4 versions

Prior to v10.6, example `parameterisations/gflash/gflash1` was `parameterisations/gflash/`.

Set of examples is extended, to present different options:

Example	`gflash1`	`gflash2`	`gflash3`
Block of homogeneous material	mass geo	mass geo	mass geo
Crystals (readout geometry)	mass geo	mass geo	parallel geo
Sensitive detector	mass geo	mass geo	parallel geo
Envelope for parameterisation	mass geo	parallel geo	mass geo

Additionally, `examples/extended/parameterisations/gflash/gflasha` contains simple post-event analysis of shower shapes.

All examples feature parametrisation of the same homogeneous calorimeter, only technical details change.

Example 4

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

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- $f(t)$ and $f(r)$ parametrised as a function of particle's energy (E) and medium (Z)

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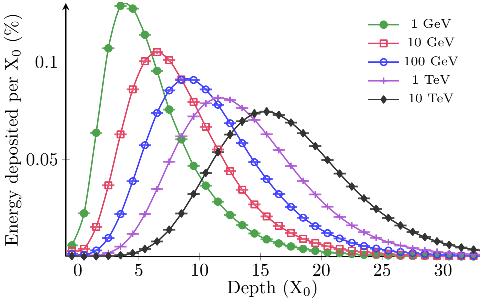
- flat distribution in azimuthal angle $f(\varphi) = \frac{1}{2\pi}$
- $f(t)$ and $f(r)$ parametrised as a function of particle's energy (E) and medium (Z)
- t and r are expressed in units of X_0 and R_M

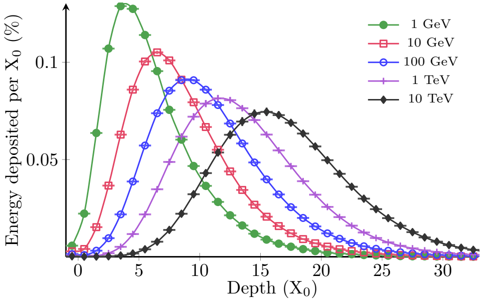
Example 4 - longitudinal profile

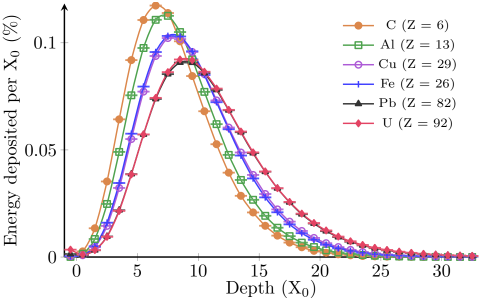
examples/extended/parameterisations/gflash/gflash1



$$T \sim \ln E$$

Example 4 - longitudinal profile





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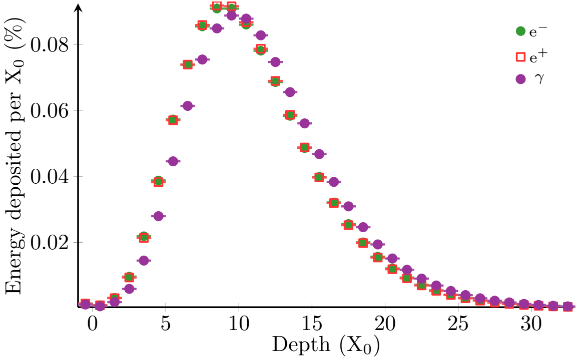
Energy deposited per X_0 (%)
0.08
0.06
0.04
0.02
0
5
10
15
20
25
30
Depth (X_0)
e^-
e^+
γ

Example 4 - 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 $y = \frac{E}{E_c}$:

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

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A.1 Homogeneous Media

A.1.1 Average longitudinal profiles

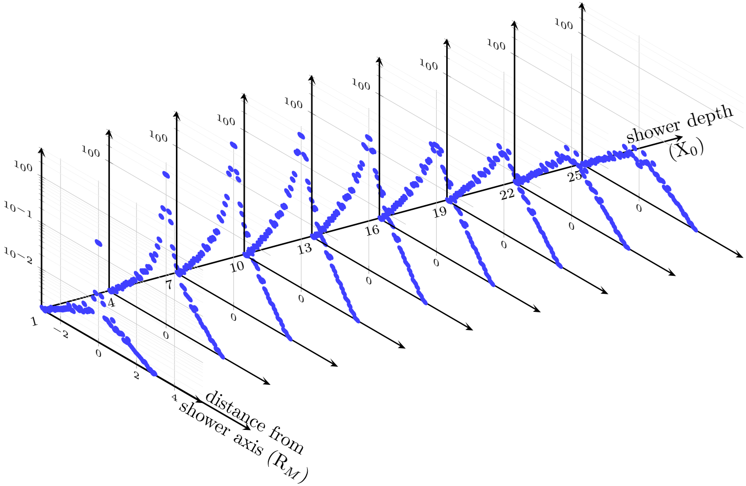
$$T_{hom} = \ln y - 0.858$$
$$\alpha_{hom} = 0.21 + (0.492 + 2.38/Z) \ln y$$

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 4 – lateral profile



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

Example 4 – lateral profile

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

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

$$= p \frac{2 r R_{\text{core}}^2}{\left(r^2 + R_{\text{core}}^2\right)^2} + (1-p) \frac{2 r R_{\text{tail}}^2}{\left(r^2 + R_{\text{tail}}^2\right)^2}$$

Example 4 – lateral profile

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

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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 4 – 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 4 – 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();
  fFastShowerModel->SetHitMaker(*fHitMaker);
  G4cout«"end shower parameterization."«G4endl;
  // **********************************************
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Example 4 – model

ExGflashDetectorConstruction.cc

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void ExGflashDetectorConstruction::ConstructSDandField()
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  fCrystal_log->SetSensitiveDetector(CaloSD);

  // Get nist material manager
  G4NistManager* nistManager = G4NistManager::Instance();
  G4Material*          pbW04 = nistManager->FindOrBuildMaterial("G4_PbW04");
  // -- fast simulation models:
  // **********************************************
  // * Initializing shower modell
  // ***********************************************
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  SDman->AddNewDetector(CaloSD);
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  // **********************************************
}
```

Example 4 – 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
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Example 4 – model

ExGflashSensitiveDetector.hh

```
class ExGflashSensitiveDetector: public G4VSensitiveDetector,
                                 public G4VGFlashSensitiveDetector {
              ...
              virtual G4bool ProcessHits(G4Step*,G4TouchableHistory*);
              virtual G4bool ProcessHits(G4GFlashSpot*aSpot,G4TouchableHistory*);
              ...
};
```

Example 4 – model

examples/extended/parameterisations/gflash/gflash1

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

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

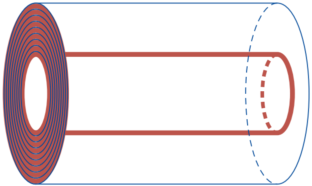
Sampling calorimeter For simulation in sampling detectors use GFlashSamplingShowerParameterisation and GFlashSamplingShowerTuning. Readout should collect signal from both active and pasive material (e.g. by constructing SD in parallel world). Those calorimeters have not been tested in Geant4, so implementation of GFlash in Geant4 may require further work (which is on-going).

Example 5:

examples/extended/parameterisations/Par04

Example 5

- `examples/extended/parameterisations/Par04` new example since Geant4 11.0 release
- WIP in public repo on gitlab
- Detector geometry is simplistic and easy to configure
- Collider-style concentric cylinders with up to two materials (active and optionally passive)



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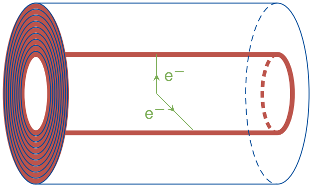
- Collider-style concentric cylinders with up to two materials (active and optionally passive)
- Particle direction and position is measured at the entrance to calorimeter
  - many possible ways to do it
  - we chose to trigger on a fast sim model that is attached to calorimeter
  - LHCb's approach: introduce SD and store hits



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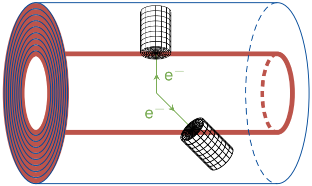

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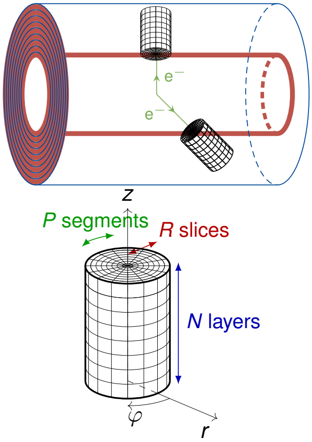
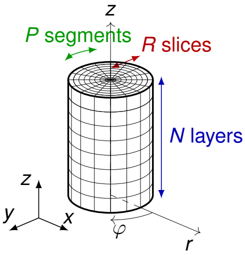
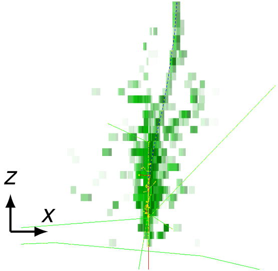
- Scoring of energy deposits relative to the particle direction
- Similar granularity 'pictures' obtained independently on angle
- Granularity of shower deposition is configurable



Example 5 – EM showers



10 GeV electron



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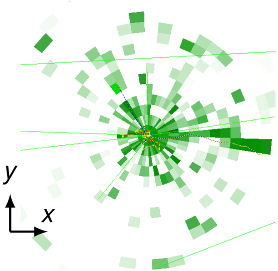
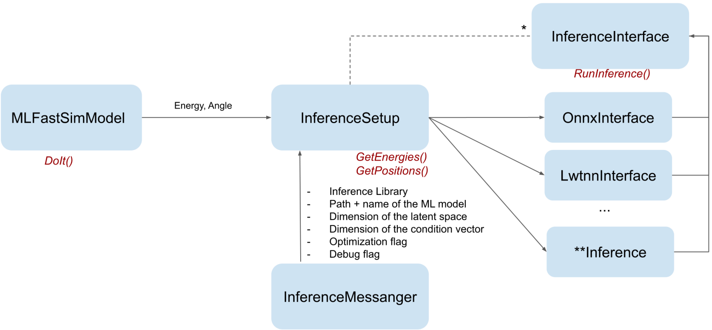
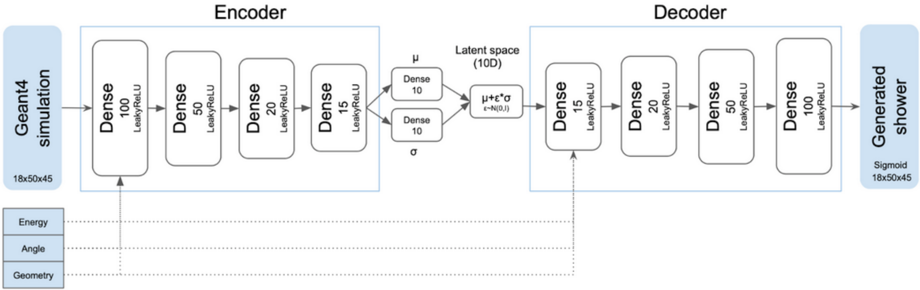


- Example uses 0.3 mm Si and 1.4 mm W layers
- Readout granularity is $\Delta r \times \Delta\varphi \times \Delta z = 2.3\,\text{mm} \times \frac{2\pi}{50} \times 3.4\,\text{mm}$ aiming for $\Delta r \approx 0.25\,R_M$ and $\Delta z \approx 0.6\,X_0$
- Number of readout cells is $R \times P \times N = 18x50x45$ aiming for 98% containment of 1 TeV particles
- **Open access dataset for SiW (and scintillator-Pb) released 10.5281/zenodo.6082201**
- This dataset is a base of ML studies, including CaloChallenge.

Example 5 – inference within C++ framework

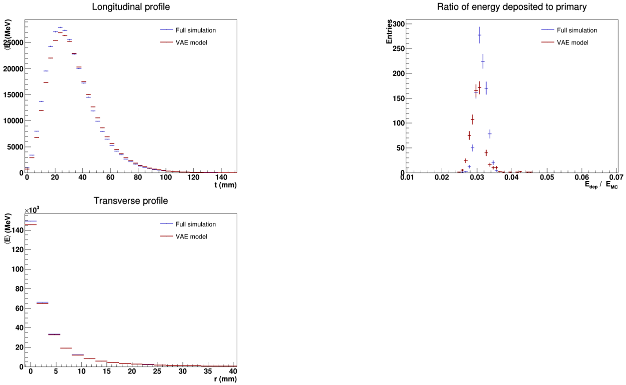


- Demonstrates how to incorporate inference libraries (ONNX Runtime, LWTNN, Torch since G4 11.1) that should be general enough for users to copy (one of) them, same with `MLFastSimModel`
- The user configuration (pre/post processing, IDs →(xyz)) is done via `InferenceSetup`



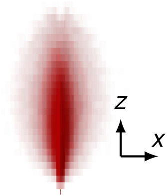
Variational autoencoder that is a subject of study in our group. Provided model is trained on the specified geometry, it **requires changes with the changes to the geometry**.

Example 5 – generated showers with VAE

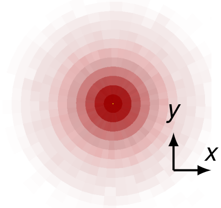


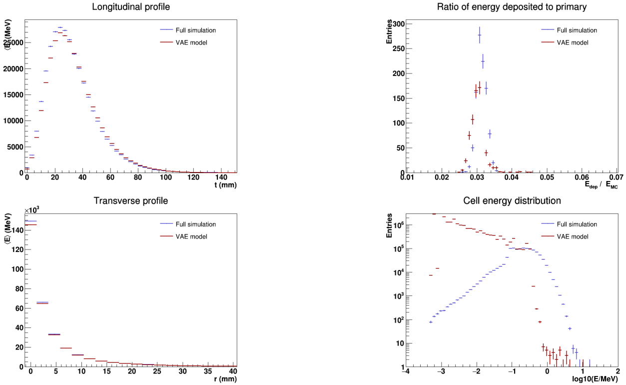
- Resonably good average distributions

Example 5 – generated showers with VAE



10 GeV electron

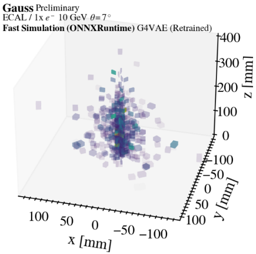




- Resonably good average distributions
- but VAE models can lead to smeared/blurry pictures
- Effect is negligible in low-granularity calorimeters, e.g. ATLAS: a similar VAE is presented in the CaloChallenge
- . . . but will be visible for high-granularity detectors

Real life example – generated showers with VAE

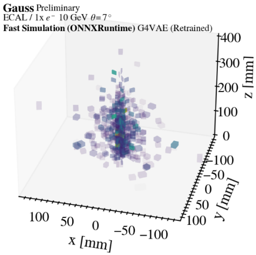
- Par04 workflow implemented in Gaussino (LHCb's simulation framework)
- VAE model with additional sampling step models EM showers



source: M.Mazurek ACAT 2024

Real life example – generated showers with VAE

- Par04 workflow implemented in Gaussino (LHCb's simulation framework)
- VAE model with additional sampling step models EM showers
- Recent results presented at ACAT 2024 and soon also at CHEP 2024



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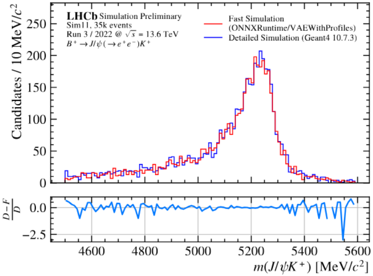

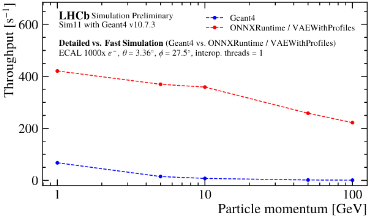

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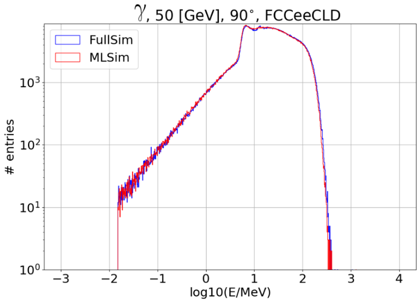
Example 5 - other models: CaloDiT

CaloDiT model - the currently developed (diffusion) model in our group, which much better models cell energy;



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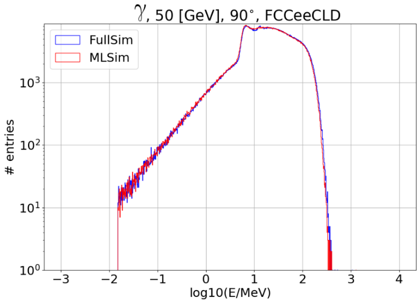
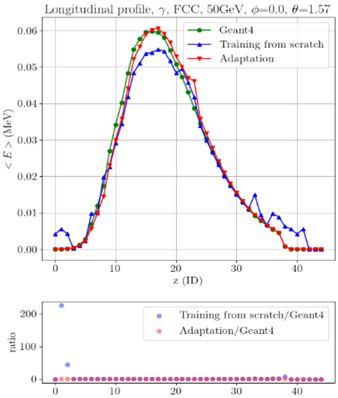


source: A. Zaborowska FCC Physics Week 2024

Our focus is not only on the model development for single geometry, but also on its **adaptation capabilities** when tried for a new detector.

200K samples



source: P. Raikwar ACAT 2024

with preliminary tests:

- 25 × faster,
- 5 × less data needed for training.

Example 5 - many other models

- **Open doors to other ML models**: many models were developed by over 60 participants within CaloChallenge.
- 16 different (publically available!) models submitted and ready to use with Par04-like mesh segmentation!
- Review of those models soon published! almost 200 pages!
- Stay tuned for ML4jets 2024 presentation

Review Article

CaloChallenge 2022: A Community Challenge for Fast Calorimeter Simulation

"Calorimeter Simulation", generated via midjourney, 2022

Claudius Krause[1,2] (main editor),
Michele Faucci Giannelli[3,4] (editor), Gregor Kasieczka[5] (editor),
Benjamin Nachman[6] (editor), Dalila Salamani[7] (editor),
David Shih[8] (editor), Anna Zaborowska[7] (editor),

Oz Amram[9], Kerstin Borras[10,11], Matthew R. Buckley[8],
Erik Buhmann[5], Thorsten Buss[5,10],
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Jesse C. Cresswell[12], Sascha Diefenbacher[6], Etienne Dreyer[15],
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Luigi Favaro[2], Matteo Franchini[13,14], Frank Gaede[10],
Eilam Gross[15], Shih-Chieh Hsu[17], Kristina Jaruskova[7],
Benno Käch[5,10], Jayant Kalagnanam[18], Raghav Kansal[9,19],
Taewoo Kim[12], Dmitrii Kobylianskii[15], Anatolii Korol[10],
William Korcari[5], Dirk Krücker[10], Katja Krüger[10],
Marco Letizia[20,21], Shu Li[22,23,24], Qibin Liu[22,23,24], Xiulong Liu[17],

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Questions/problems/ideas? anna.zaborowska@cern.ch