



# Physics Biasing

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# Outline

- **Biassing in Hadronic Physics**
  - First part: the “old” way
  - Second part: the “new”, recommended way
- Exercises



The “old” approach

# Built-in Biasing in Hadronics

- Radioactive Decay
  - Via UI commands (see today's lecture "Hadronic Physics II" )
- Cross Sections
  - Possibility to scale any hadronic cross section via the method `G4HadronicProcess::BiasCrossSectionByFactor( G4double aScale )`
  - No UI commands available: need to write some user code to call it, e.g. `theMuonNuclearProcess->BiasCrossSectionByFactor( 1000.0 );`
- Leading Particle Biasing
  - At each hadronic interaction, keep only the most energetic particle (and randomly one particle of each species: meson, baryon,  $\pi^0$ ,  $\gamma$ ) via the method: `G4HadFinalState* G4HadLeadBias::Bias( G4HadFinalState* result )`
  - No UI commands available: need to modify the `PostStepDoIt` method of the hadronic processes (to which we want to apply this biasing) to create an instance of the class `G4HadLeadBias` and call its `Bias` method

# Built-in Biasing in Hadronics

- Radioactive Decay

OK

- Via UI commands (see before)

- Cross Sections

**Need to write some user code...**

- Possibility to scale any hadronic cross section via the method `G4HadronicProcess::BiasCrossSectionByFactor( G4double aScale )`
- No UI commands available : need to write some user code to call it, e.g. `theMuonNuclearProcess->BiasCrossSectionByFactor( 1000.0 );`

- Leading Particle Biasing

**Complicated to use in practice !**

- At each hadronic interaction, keep only the most energetic particle (and randomly one particle of each species: meson, baryon,  $\pi^0$ ,  $\gamma$ ) via the method: `G4HadFinalState* G4HadLeadBias::Bias(...)`
- No UI commands available: need to modify the `PostStepDoIt` method of the hadronic processes (to which we want to apply this biasing) to create an instance of the class `G4HadLeadBias` and call its `Bias` method

# Example of biasing a cross section (1/2)

```
int main( ... ) {  
    ...  
    G4VModularPhysicsList* physicsList = new FTFP_BERT;  
    physicsList->RegisterPhysics( new MySpecialPhysicsConstructor );  
    runManager->SetUserInitialization( physicsList );  
    ...  
}
```

```
class MySpecialPhysicsConstructor : public G4VPhysicsConstructor {  
    public:  
    ...  
    virtual void ConstructParticle() {};  
    virtual void ConstructProcess();  
    ...  
};
```

# Example of biasing a cross section (2/2)

```
void MySpecialPhysicsConstructor::ConstructProcess() {  
    G4HadronicProcess* theInelasticProcess = nullptr;  
    G4ProcessVector* pvec =  
        G4MuonMinus::MuonMinus()->GetProcessManager()->GetProcessList();  
    for ( size_t i = 0; i < pvec->size(); i++ ) {  
        if ( (*pvec)[i]->GetProcessName() == "muonNuclear" ) {  
            theInelasticProcess = static_cast< G4HadronicProcess* >( (*pvec)[i] );  
            break;  
        }  
    }  
    if ( theInelasticProcess ) {  
        theInelasticProcess->BiasCrossSectionByFactor( 1000.0 );  
    }  
}
```

# Leading Particle Biasing and Beyond...

- Much simpler and neat to use the “generic biasing” approach
- Moreover, “generic biasing” allows to do much more :
  - Cross section biasing
  - Force collision biasing
  - Geometry-based biasing
    - Including the possibility to use parallel geometries
  - Hadronic-model per region
  - ...





The “new” approach

# Generic Bias for Hadronics (1/2)

- This is the new and recommended approach for biasing in Geant4 – not only for hadronics !

- Allow to mix biasing options via “building blocks” (instead of built-in functionalities)

- Examples available in:

*examples/extended/biasing/* and *examples/extended/hadronic/*

we discuss here the following ones (relevant for hadronics):

1. **GB01/** : cross-sections biasing (*i.e.* changing the natural cross sections)
2. **GB02/** : force-collision biasing (*i.e.* forcing an interaction in a volume)
3. **GB07/** : leading-particle biasing (*i.e.* keep leading particle and one particle per species)
4. **Hadr08/** : hadronic-model per-region (*i.e.* using a different hadronic model in a region)

# Generic Bias for Hadronics (2/2)

- Notes:

- There is plenty of user code, but nearly all of it can be re-used: only a tiny part needs to be customized per use-case!
- When dealing with biasing, you need to take into account the **statistical weight** of a track, which can be obtained as:

***w = track->GetWeight()***

at any level (e.g. stepping action or sensitive detector)

# Cross-Section Generic Biasing – GB01

```
int main( ... ) {
```

```
    ...  
    FTFP_BERT* physicsList = new FTFP_BERT;  
    G4GenericBiasingPhysics* biasingPhysics = new G4GenericBiasingPhysics;  
    biasingPhysics->Bias( "gamma" );  
    biasingPhysics->Bias( "neutron" );  
    physicsList->RegisterPhysics( biasingPhysics );
```

Enable biasing only for a subset of particle types

```
    ...  
}  
  
void GB01DetectorConstruction::ConstructSDandField() {
```

```
    ...  
    GB01BOptrMultiParticleChangeCrossSection* biasingOperator =  
        new GB01BOptrMultiParticleChangeCrossSection;  
    biasingOperator->AddParticle( "gamma" );  
    biasingOperator->AddParticle( "neutron" );  
    biasingOperator->AttachTo( logicVolumeToBias );
```

Possible to define cross-section biasing for sets of particle types in specified logical volumes

```

class GB01BOptrMultiParticleChangeCrossSection : public G4VBiasingOperator {
public:
    ...
    void AddParticle( G4String particleName );
    void StartTracking( const G4Track* track );
private:
    virtual G4VBiasingOperation* ProposeOccurrenceBiasingOperation(...);
    virtual void OperationApplied(...);
    ...
    std::map< const G4ParticleDefinition*, GB01BOptrChangeCrossSection* > fBOptrForParticle;
    std::vector< const G4ParticleDefinition* > fParticlesToBias;
    GB01BOptrChangeCrossSection* fCurrentOperator;
    G4int fnInteractions;
};

void GB01BOptrMultiParticleChangeCrossSection::AddParticle( G4String particleName ) {
    const G4ParticleDefinition* particle = G4ParticleTable::GetParticleTable()->FindParticle( particleName );
    ...
    GB01BOptrChangeCrossSection* opr = new GB01BOptrChangeCrossSection( particleName );
    fParticlesToBias.push_back( particle );
    fBOptrForParticle[ particle ] = opr;
}

void GB01BOptrMultiParticleChangeCrossSection::StartTracking( const G4Track* track )
    // Fetch the underneath biasing operator, if any, for the current particle type and store it in fCurrentOperator
}

```

```

G4VBiasingOperation* GB01BOptrMultiParticleChangeCrossSection::
ProposeOccurenceBiasingOperation( const G4Track* track,
                                   const G4BiasingProcessInterface* callingProcess ) {
    // Examples of limitations imposed to apply the biasing:
    if ( track->GetParentID() != 0 ) return 0; // Limit application of biasing to primary particles only
    if ( fnInteractions > 4 ) return 0; // Limit to at most 5 biased interactions
    if ( track->GetWeight() < 0.05 ) return 0; // Limit to a weight of at least 0.05
    if ( fCurrentOperator ) return fCurrentOperator->
        GetProposedOccurenceBiasingOperation( track, callingProcess );
    else return 0;
}

void GB01BOptrMultiParticleChangeCrossSection::OperationApplied(...) {
    fnInteractions++; // Count number of biased interactions
    // Inform the underneath biasing operator that a biased interaction occurred:
    if ( fCurrentOperator ) fCurrentOperator->ReportOperationApplied(...);
}

```

```

class GB01BOptrChangeCrossSection : public G4VBiasingOperator {
public:
    GB01BOptrChangeCrossSection( G4String particleToBias, G4String name = "ChangeXS" );
    ...
    virtual void StartRun();
private:
    virtual G4VBiasingOperation* ProposeOccurenceBiasingOperation(...);
    ...
    using G4VBiasingOperator::OperationApplied;
    virtual void OperationApplied(...);
    std::map< const G4BiasingProcessInterface*, G4BOptrChangeCrossSection* > fChangeCrossSectionOperations;
    const G4ParticleDefinition* fParticleToBias;
};

void GB01BOptrChangeCrossSection::StartRun() {
    const G4ProcessManager* processManager = fParticleToBias->GetProcessManager();
    const G4BiasingProcessSharedData* sharedData = G4BiasingProcessInterface::GetSharedData( processManager );
    for ( size_t i = 0 ; i < (sharedData->GetPhysicsBiasingProcessInterfaces()).size(); i++ ) {
        const G4BiasingProcessInterface* wrapperProcess = (sharedData->GetPhysicsBiasingProcessInterfaces())[i];
        G4String operationName = "Xschange-" + wrapperProcess->GetWrappedProcess()->GetProcessName();
        fChangeCrossSectionOperations[ wrapperProcess ] = new G4BOptrChangeCrossSection( operationName );
    }
}

```

```

G4VBiasingOperation* GB01BOptrChangeCrossSection::ProposeOccurenceBiasingOperation(...) {
    if ( track->GetDefinition() != fParticleToBias ) return 0;
    G4double analogInteractionLength =
        callingProcess->GetWrappedProcess()->GetCurrentInteractionLength();
    if ( analogInteractionLength > DBL_MAX/10.0 ) return 0;
    G4double analogXS = 1.0/analogInteractionLength;
    G4BOptrChangeCrossSection* operation = fChangeCrossSectionOperations[ callingProcess ];
    ...
    operation->SetBiasedCrossSection( 10.0 * analogXS ); //<--- Scaling factor for the xsec !
    operation->Sample();
    ...
    return operation;
}

```

Alternatively, one could use different cross section scaling factors according to the particle type and/or process type

```

void GB01BOptrChangeCrossSection::OperationApplied(...) {
    G4BOptrChangeCrossSection* operation = fChangeCrossSectionOperations[ callingProcess ];
    if ( operation == occurrenceOperationApplied ) operation->SetInteractionOccured();
}

```



# Force-Collision Generic Biasing – GB02

- It forces a process to occur in a given volume for a given particle type
- Useful, for instance, when you are interested to study hadronic inelastic interactions in a thin or light target
  - Currently adapted to neutral particles, but the extension to charged particles is in our plan of work
- Be careful: in its present form, it forces the occurrence of any of the processes associated to the particle type we want to bias, maintaining the relative probabilities (e.g. cross sections) of these processes
  - For instance, for a neutron on a thin layer of Silicon, one of the following 4 processes can occur: elastic, capture, fission, inelastic
  - In future versions, there might be the feature of forcing only the inelastic process

```
int main( ... ) {  
    ...  
    FTFP_BERT* physicsList = new FTFP_BERT;  
    G4GenericBiasingPhysics* biasingPhysics = new G4GenericBiasingPhysics;  
    biasingPhysics->Bias( "gamma" );  
    biasingPhysics->Bias( "neutron" );  
    physicsList->RegisterPhysics( biasingPhysics );  
    ...  
}
```

```
void GB02DetectorConstruction::ConstructSDandField() {  
    ...  
    GB02BOPtrMultiParticleForceCollision* biasingOperator =  
        new GB02BOPtrMultiParticleForceCollision;  
    biasingOperator->AddParticle( "gamma" );  
    biasingOperator->AddParticle( "neutron" );  
    biasingOperator->AttachTo( logicVolumeToBias );  
}
```

```

class GB02BOptrMultiParticleForceCollision : public G4VBiasingOperator {
public:
    ...
    void AddParticle( G4String particleName ); // Declare particles to be biased
    virtual void StartTracking( const G4Track* track );
private:
    virtual G4VBiasingOperation* ProposeNonPhysicsBiasingOperation(...);
    virtual G4VBiasingOperation* ProposeOccurenceBiasingOperation(...);
    virtual G4VBiasingOperation* ProposeFinalStateBiasingOperation(...);
    void OperationApplied(...);
    void ExitBiasing(...);
    std::map< const G4ParticleDefinition*, G4BOptrForceCollision* > fBOptrForParticle;
    std::vector< const G4ParticleDefinition* > fParticlesToBias;
    G4BOptrForceCollision* fCurrentOperator;
};

```

```

void GB02BOptrMultiParticleForceCollision::AddParticle( G4String particleName ) {
    const G4ParticleDefinition* particle = G4ParticleTable::GetParticleTable()->FindParticle( particleName );
    if ( particle == 0 ) { ... } // just warning exception and return
    G4BOptrForceCollision* optr =
        new G4BOptrForceCollision( particleName, "ForceCollisionFor" + particleName );
    fParticlesToBias.push_back( particle );
    fBOptrForParticle[ particle ] = optr;
}

```

```
G4VBiasingOperation* GB02BOPtrMultiParticleForceCollision::ProposeOccurenceBiasingOperation(...) {
    if ( fCurrentOperator ) return fCurrentOperator->GetProposedOccurenceBiasingOperation( track, callingProcess );
    else                    return 0;
}
```

Possible to impose here some limitations on when to apply biasing,  
e.g. only for a certain process type

```
G4VBiasingOperation* GB02BOPtrMultiParticleForceCollision::ProposeFinalStateBiasingOperation(...) {
    if ( fCurrentOperator ) return fCurrentOperator->GetProposedFinalStateBiasingOperation( track, callingProcess );
    else                    return 0;
}
```

```
void GB02BOPtrMultiParticleForceCollision::StartTracking( const G4Track* track ) {
    const G4ParticleDefinition* definition = track->GetParticleDefinition();
    std::map< const G4ParticleDefinition*, G4BOPtrForceCollision* >::iterator it = fBOPtrForParticle.find( definition );
    fCurrentOperator = 0;
    if ( it != fBOPtrForParticle.end() ) fCurrentOperator = (*it).second;
}
```

```
void GB02BOPtrMultiParticleForceCollision::OperationApplied(...) {
    if ( fCurrentOperator ) fCurrentOperator->ReportOperationApplied(...);
}
```

```
void GB02BOPtrMultiParticleForceCollision::OperationApplied(...) {
    if ( fCurrentOperator ) fCurrentOperator->ReportOperationApplied(...);
}
```

```
void GB02BOPtrMultiParticleForceCollision::ExitBiasing(...) {
    if ( fCurrentOperator ) fCurrentOperator->ExitingBiasing( track, callingProcess );
}
```

# Leading-Particle Generic Biasing – GB07

- Useful technique, in particular for shielding applications
- In an interaction, this biasing scheme returns a reduced set of secondaries: the most energetic secondary (called the “leading” particle, with weight equals to 1.0) and one secondary randomly chosen for each species (with weight given by the inverse of the number of secondaries of each species)
  - Particles and anti-particles are considered to belong to the same “species”
  - There is a further option – not used in our example – to apply a further reduction of the secondaries via Russian roulette, useful for electron/positron bremsstrahlung emission, positron annihilation, and  $\pi^0$  decay

```
int main( ... ) {
```

```
...
```

```
FTFP_BERT* physicsList = new FTFP_BERT;
```

```
G4GenericBiasingPhysics* biasingPhysics = new G4GenericBiasingPhysics;
```

```
std::vector< G4String > protonProcessesToBias;
```

```
protonProcessesToBias.push_back( "protonInelastic" );
```

```
biasingPhysics->PhysicsBias( "proton", protonProcessesToBias );
```

```
physicsList->RegisterPhysics( biasingPhysics );
```

```
...
```

```
}
```

Specify which particles to bias  
and, for each of them, which  
processes to bias

```
void GB07DetectorConstruction::ConstructSDandField() {
```

```
...
```

```
GB07BOPtrLeadingParticle* biasingOperator = new GB07BOPtrLeadingParticle;
```

```
biasingOperator->AttachTo( logicVolumeToBias );
```

```
...
```

```
}
```

```

class GB07BOptrLeadingParticle : public G4VBiasingOperator {
public:
    GB07BOptrLeadingParticle( G4String operatorName = "LeadingParticleBiasingOperator");
    virtual ~GB07BOptrLeadingParticle();
    virtual void StartRun() final;
    virtual void StartTracking( const G4Track* track ) final;

private:
    // Mandatory from base class: Unused:
    virtual G4VBiasingOperation* ProposeNonPhysicsBiasingOperation(...) final { return nullptr; }
    virtual G4VBiasingOperation* ProposeOccurenceBiasingOperation (...) final { return nullptr; }

    // Mandatory from base class: Used:
    // Will return the biasing operation at the final state generation stage
    virtual G4VBiasingOperation* ProposeFinalStateBiasingOperation( const G4Track* track,
                                                                    const G4BiasingProcessInterface* callingProcess ) final;

    // The leading particle biasing operation that will actually trim the final state generation:
    G4BOptrLeadingParticle* fLeadingParticleBiasingOperation;
};

```

```
GB07BOptrLeadingParticle::GB07BOptrLeadingParticle( G4String operatorName ) :  
    G4VBiasingOperator( operatorName ) {  
    fLeadingParticleBiasingOperation = new G4BOptnLeadingParticle( "LeadingParticleBiasingOperation" );  
}
```

```
GB07BOptrLeadingParticle::~~GB07BOptrLeadingParticle() {  
    delete fLeadingParticleBiasingOperation;  
}
```

```
GB07BOptrLeadingParticle::  
ProposeFinalStateBiasingOperation( const G4Track*, const G4BiasingProcessInterface* callingProcess ) {  
    fLeadingParticleBiasingOperation->SetFurtherKillingProbability( -1.0 );  
    return fLeadingParticleBiasingOperation;  
}
```



# Hadronic-model per-region – *Hadr08*

- Geant4 does not allow physics lists per region.  
However, it is possible to specify “EM models per region”.  
But the hadronic framework does not allow hadronic models per region
- This final example shows how it is possible to achieve in practice “HAD models per region” by using “generic biasing”
  - We use the powerful "generic biasing" machinery available in Geant4, but the actual weights of all tracks remain to the usual value (1.0) as in the normal (unbiased) case
  - In our example (inspired by a real application in ALICE) we want to use the physics list FTFP\_BERT everywhere, except in the Tracker region, where we want to use the a more accurate but slower intra-nuclear cascade model, INCLXX, instead of BERT
    - In the case of ALICE, replacing FTFP\_BERT with FTFP\_INCLXX would slow down the performance of the simulation by a factor of 2, whereas with this trick they can keep practically the same computing performance

```
int main( ... ) {  
    ...  
    FTFP_BERT* physicsList = new FTFP_BERT;  
    G4GenericBiasingPhysics* biasingPhysics = new G4GenericBiasingPhysics;  
    biasingPhysics->Bias( "proton" );  
    physicsList->RegisterPhysics( biasingPhysics );  
    ...  
}
```

```
void DetectorConstruction::ConstructSDandField() {  
    ...  
    BiasingOperator* biasingOperator = new BiasingOperator;  
    biasingOperator->AddParticle( "proton" );  
    biasingOperator->AttachTo( trackerLogicalVolume );  
}
```

```

class BiasingOperator : public G4VBiasingOperator {
public:
    BiasingOperator();
    virtual ~BiasingOperator() {}
    void AddParticle( G4String particleName );
    virtual G4VBiasingOperation* ProposeFinalStateBiasingOperation( const G4Track* track,
                                                                    const G4BiasingProcessInterface* callingProcess ) final;

    // Not used:
    virtual G4VBiasingOperation* ProposeNonPhysicsBiasingOperation(...) { return 0; }
    virtual G4VBiasingOperation* ProposeOccurenceBiasingOperation(...) { return 0; }

private:
    std::vector< const G4ParticleDefinition* > fParticlesToBias;
    BiasingOperation* fBiasingOperation;
};

```

```
BiassingOperator::BiassingOperator() : G4VBiasingOperator( "BiassingOperator" ) {  
    fBiassingOperation = new BiassingOperation( "BiassingOperation" );  
}
```

```
void BiassingOperator::AddParticle( G4String particleName ) {  
    const G4ParticleDefinition* particle = G4ParticleTable::GetParticleTable()->FindParticle( particleName );  
    ... // check that particle is not nullptr  
    fParticlesToBias.push_back( particle );  
}
```

```
G4VBiasingOperation* BiassingOperator::ProposeFinalStateBiassingOperation( const G4Track* ,  
                                                                           const G4BiassingProcessInterface* callingProcess ) {  
    // Apply the biasing operation only for proton inelastic process  
    if ( callingProcess && callingProcess->GetWrappedProcess() &&  
        callingProcess->GetWrappedProcess()->GetProcessName() == "protonInelastic" ) {  
        return fBiassingOperation;  
    } else {  
        return 0;  
    }  
}
```

```

class BiasingOperation : public G4VBiasingOperation {
public:
    ...
    virtual G4VParticleChange* ApplyFinalStateBiasing(...);

    // Unused :
    virtual const G4VBiasingInteractionLaw* ProvideOccurenceBiasingInteractionLaw( ...) { return 0; }
    virtual G4double DistanceToApplyOperation( ...) { return DBL_MAX; }
    virtual G4VParticleChange* GenerateBiasingFinalState(...) { return 0; }

private:
    G4HadronInelasticProcess* fProtonInelasticProcess;
};

BiasingOperation::BiasingOperation( G4String name ) : G4VBiasingOperation( name ) {
    fProtonInelasticProcess = new G4HadronInelasticProcess( "protonInelastic", G4Proton::Definition() );
    // Create hadronic models and cross sections for the alternative "FTFP_INCLXX" configuration
    // to be used only in the TrackerLogicalVolume , and register them in fProtonInelasticProcess
    ...
}

G4VParticleChange* BiasingOperation::ApplyFinalStateBiasing( const G4BiasingProcessInterface* ,
                                                             const G4Track* track, const G4Step* step, G4bool& ) {
    if ( track->GetParticleDefinition() == G4Proton::Definition() ) {
        return fProtonInelasticProcess->PostStepDolt( *track, *step );
    }
}

```



# Exercises

# Exercise : Generic Biasing (1/2)

- Consider the example:
  - *geant4/examples/extended/biasing/GB01*
- Run the example (using for instance as input *exampleGB01.in* ) and compare the following 4 modes:
  1. As it is, with biased cross sections for all gamma and neutron processes
  2. Bias  $\times 100$  the cross sections of all gamma processes and  $\times 200$  the cross sections of all neutron processes
    - Look at the method *ProposeOccurenceBiasingOperation ...*
  3. Keep biasing cross sections only for gamma, but not for neutron
    - Simple: it is enough to comment one line...
  4. Bias the cross section only for the “*photonNuclear*” gamma process
    - Check the name of the wrapped process:  
*callingProcess -> GetWrappedProcess() -> GetProcessName()*

# Exercise : Generic Biasing (2/2)

- Consider the example:
  - *geant4/examples/extended/biasing/GB02*
- Run the example (using for instance as input *exampleGB02.in* ) and compare the following 4 modes:
  1. As it is, with forced interaction for all gamma and neutron processes
  2. Apply biasing only for the “*photonNuclear*” gamma process
    - Check the name of the wrapped process  
*callingProcess -> GetWrappedProcess() -> GetProcessName()*