Geant4: A Simulation toolkit

O. Stézowski and A. Cazes

With many thanks to the Geant4 community !!!!

The roadmap of the week

Why?

Those slides

4 documents
And
Practical sessions

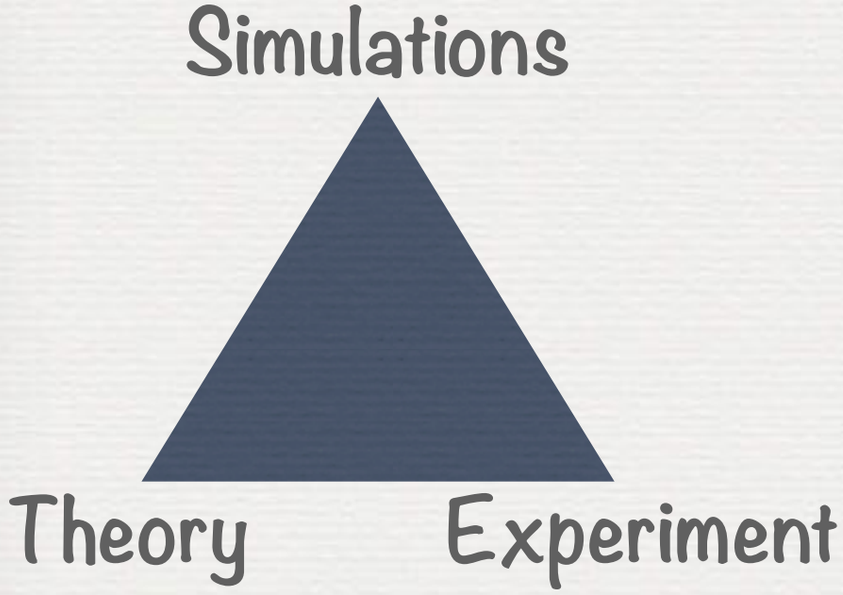
Geant 4

A personal, general view

More practical reasons

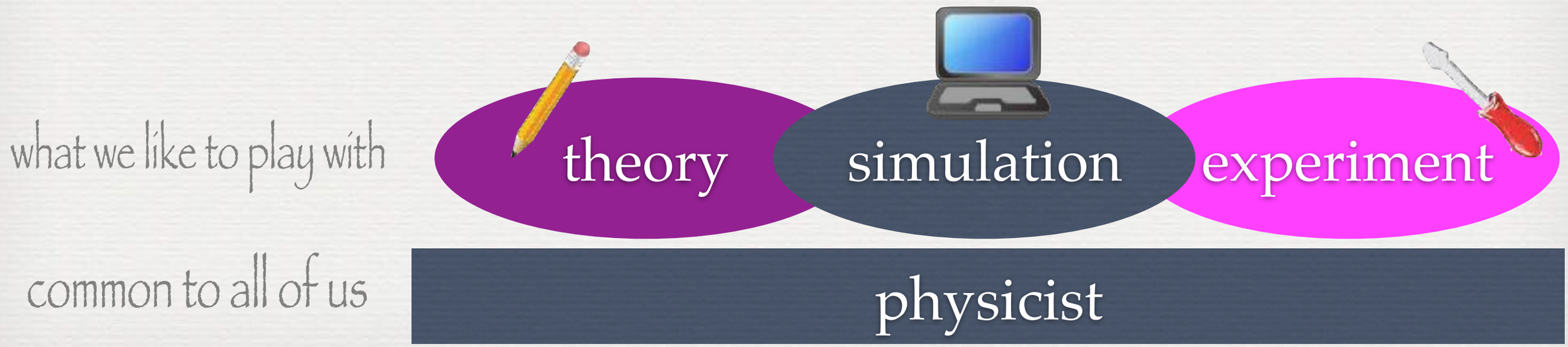
Why?

Why simulations ...



A guy, a seminar, somewhere:
place of simulations in physics

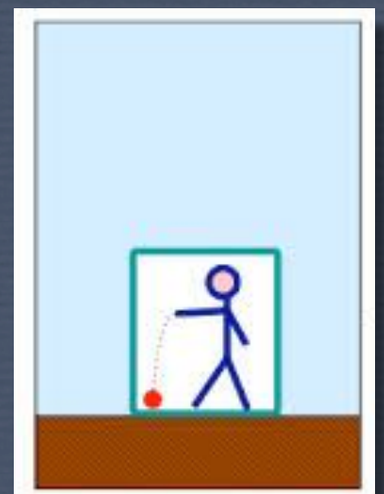
My View



Why?

Why simulations ...

Though experiment !!



What if I change ...

theory

simulation

experiment

what we like to play with

common to all of us

physicist

Why simulations ...

- It allows to be:
  - less expensive
  - quicker ... well may be not ...
  - less dangerous
  - ...

- It allows to control everything:
  - cause ☛ effect relationship
  - step by step, more and more complexity
  - step by step, more and more realism
  - ...

A personal, general view

More practical reasons

Why?

In our 'field', particles ...

interaction with matter:
process(es), σ

detectors

event reconstruction

signal processing

signal collection

short life

☛ new particles

particles, nuclei

my event

Why simulations for us ...

- Detectors are:
  - more and more complex / precise
  - expansive ...
  - long time for R&D phase
  - long time to have them working well

- Events to be treated are:
  - complex
  - various
  - rare for the most interesting ones (background!)

Why? Why simulations for us ...

« before » the detector is built

- to study new concepts
- establish raw performances*
- to study different triggers
- to optimize reconstructions
- to set experimental limits
- ...

➥ tools for R&D

* acceptance, response function ...

« during » the life of the detector

- to optimize experimental setup
  signal ↗, background ↘ , selection
- to understand problems in data
  lost of efficiency, resolution
- to improve signal/background
- to improve physics models
- ...

➥ to help for data analysis

➥ to understand physics

Some general statements

Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

What is It? Simulation landscape, some tools

- GEANT4 : GEometry ANd Tracking
  - ➙ http://geant4.cern.ch/

- FLUKA : FLUktuierende KAskade
  alternative to Geant4
  - ➙ http://www.fluka.org/fluka.php

- MCNP(X) : Monte-Carlo N-Particle
  More Nuclear Physics (Manhattan's project)
  - ➙ http://mcnp.lanl.gov/

Simulation landscape, many tools

EGS4, EGS5, EGSnrc
Geant3, Geant4
MARS
MCNP, MCNPX, A3MCNP, MCNP-DSP, MCNP4B
MVP, MVP-BURN
Penelope
Peregrine
Tripoli-3, Tripoli-3 A, Tripoli

DPM
EA-MC
FLUKA
GEM
HERMES
LAHET
MCBEND
MCU
MF3D
NMTC
MONK
MORSE
RTS&T-2000
SCALE
TRAX
VMC++

- pythia, herwig, hijing in particles φ
- evapor, fresco, empire in nuclear φ
- …

physics generators

What is the Geant4 toolkit ?

Geant4 is the successor of Geant3 (fortran)

The project started in Dec '94 to face the LHC challenges

- First Public release Dec '98
- Currently 2-3 public release per year
- We are going to work with version 9.6.p02 [10.0.p02]

It is a **C++** (Object Oriented language) **Monte Carlo** Simulation **Toolkit**

➥ Consequences ... ➥ basics covered in this lecture

A variety of requirements taken into account in the design for applications in:
heavy ion physics, CP violation physics, cosmic-ray physics, astrophysics, space science, medical ...

To meet such requirements, **large degree of functionality and flexibility** provided

➥ Geant4 is not only for HEP but goes well beyond that.

We know a fraction

collaborations differ

Goal: to give you enough knowledge to work in your community !

user's doc

download area

user's forum

Geant 4

Download | User Forum | Gallery
Contact Us

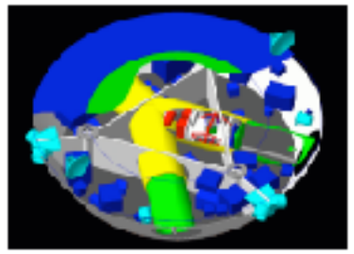
Search Geant4

Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The two main reference papers for Geant4 are published in *Nuclear Instruments and Methods in Physics Research* A 506 (2003) 250-303, and *IEEE Transactions on Nuclear Science* 53 No. 1 (2006) 270-278.

Applications

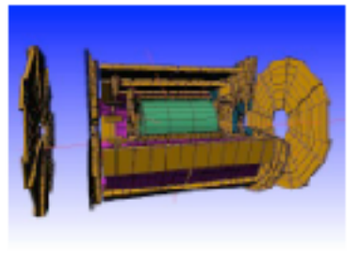
A sampling of applications, technology transfer and other uses of Geant4

User Support



Getting started, guides and information for users and developers

Results & Publications



Validation of Geant4, results from experiments and publications

Collaboration

Who we are: collaborating institutions, members, organization and legal information

News

- *28 June 2013* - **Release 10.0 BETA** is available from the Beta download area.
- *24 May 2013* - **Patch-02** to **release 9.6** is available from the download area.
- *18 March 2013* - 2013 planned developments.
- *30 October 2012* - **Patch-02** to **release 9.5** is available from the archive download area.

Events

- Geant4 2013 International User Conference on Medicine and Biology applications, Bordeaux (F
- **Past events**

news system
think your code as living 'object' !

Upgrade if needed
good practices in practical sessions

Major.Minor.[Patch]or[Beta]

Minor
- should not break your code
- new features / slightly different results

Major
- may (is likely to) break you code
- see release notes to help - warnings at running time

Patch: only bugs, no new features

Beta: to help the G4 community to develop ...

user's doc

Geant 4

Home > User Support

User Support

1. Getting started
2. Training courses and materials
3. Source code
   a. Download page
   b. LXR code browser -or- draft doxygen documentation
4. Frequently Asked Questions (FAQ)
5. Bug reports and fixes
6. User requirements tracker
7. User Forum
8. Documentation
   a. Introduction to Geant4
   b. Installation Guide
   c. Application Developers G
   d. Toolkit Developers Guid
   e. Physics Reference Manu
   f. Software Reference Mar
9. Examples
10. Physics lists
    a. Electromagnetic
    b. Hadronic
11. User Aids
    a. Tips for improving CPU
    b. Process/model catalog
    c. General particle source
12. Contact Coordinators & Contac

Geant4 User's Guide for Application

Geant4 Collaboration

Version: geant4 9.6.0

30th November, 2012

Table of Contents

pdf also

Geant 4

Geant4 Cross Reference

Search Menu:

geant4/ Browse the source code tree.

File Name Search [ ] Find
Search for files by name (case sensitive).

Full-Text Search [ ] Find
Search through all the text.

Identifier Search [ ] Find
Find a class, method, variable, etc.

Hi,

This is an interactive viewing and searching facility for the Geant4 source code.

It offers:

Source-tree browsing and file name search to easily find source files and navigate through the source directories.

Full-text indexing for fast retrieval of source files containing a given word or pattern.

Identifier cross-reference for fully hyperlinked source code. The names of classes, methods, and data can be clicked on to find the source files where they are defined and used.

The full-text indexing and retrieval are implemented using Glimpse, so all the capabilities of Glimpse are available. Please see Glimpse document for details. Note that glimpse syntax is avalible for text and identifier searches. For file name search, please use regular expression.

Note

All source files are rendered into HTML. Do not attempt to download the Geant4 source code from this site!

Links

organized in categories

user's forum

GEANT4 at hypernews.slac.stanford.edu Forum List by Category — Not Logged In (login)

Geant 4

Forums by Category | Forums by Time Order | Request a New Forum | Recent Postings | Search in Forums | Subscribe to Forums | Member Info | Members List | New Member | Overview | Contact Admin

Page Help

Category: Applications

Educational Applications | Industrial Instruments | Medical Applications | Space Applications

Category: Control of runs, events, tracks, particles

Event and Track Management | Multithreading | Particles | Run Management

Category: Experimental Setup

Biasing and Scoring | Fields: Magnetic and Otherwise | Geometry | Hits, Digitization and Pileup

Category: General matters

Documentation and Examples | HyperNews System Announcements | Hypernews Testing | Installation and Configuration
User Requirements

Category: Interfaces

(Graphical) User Interfaces | Analysis | Persistency | Visualization

Category: Physics

Biasing and Scoring | Electromagnetic Processes | Fast Simulation, Transportation & Others | Hadronic Processes
Physics List | Processes Involving Optical Photons

This site runs SLAC HyperNews version 1.11-slac-98, derived from the original HyperNews

http://hypernews.slac.stanford.edu/HyperNews/geant4/cindex

toolkit: do not hesitate to spend time in looking if things already exists !
- features / bugs known
- elegant solutions already found

Overview
Members
Activities
News
Tutorials and teachings
Conferences, workshops and meetings
Geant4 Virtual Machine
Jobs
Useful links
Publications
The Geant4-DNA project
The BioRad project
BioRad Collaboration
The BioRad II project
BioRad II Collaboration
Visualization & Qt

News front page

Geant4 9.6+P02 Virtual Machine now available for download

Download the software suite from the Geant4 for VMware section.

- Friday 31 May 2013 - Read

Geant4 2013 User Conference at the Physics-Medicine-Biology frontier

The Geant4 2013 International User Conference to be held in Bordeaux, France, from October 7th till October 11th, 2013 is announced. Registraton is open. All details are available from (...)

- Monday 11 March 2013 - Read

Geant4 9.6+P01 Virtual Machine now available for download

Download the software suite from the Geant4 for VMware section.

- Tuesday 12 February 2013 - Read

Geant4 9.6 Virtual Machine now available for download

Download the software suite from the Geant4 for VMware section.

- Thursday 13 December 2012 - Read

Two post-doctoral positions available at CENBG

For more information , please consult the Jobs section.

- Wednesday 5 December 2012 - Read

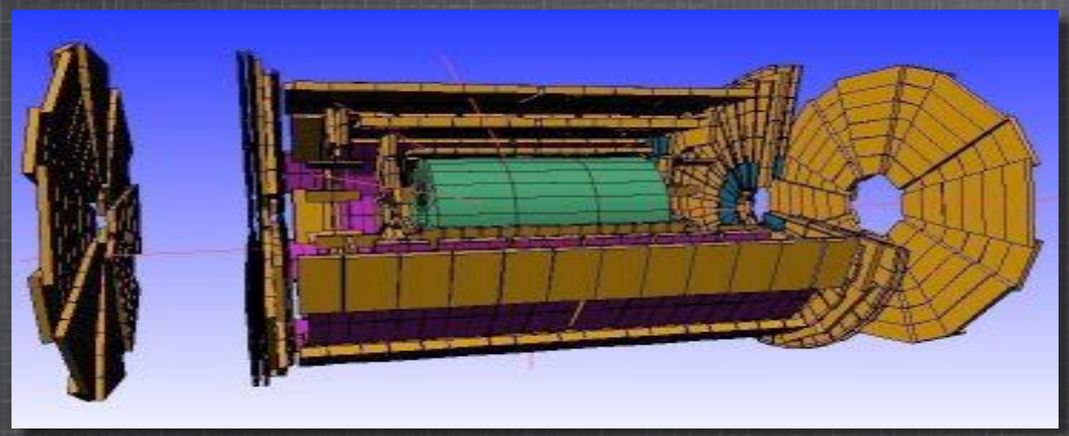
Geant4 workshop & tutorial in Wollongong U., Australia

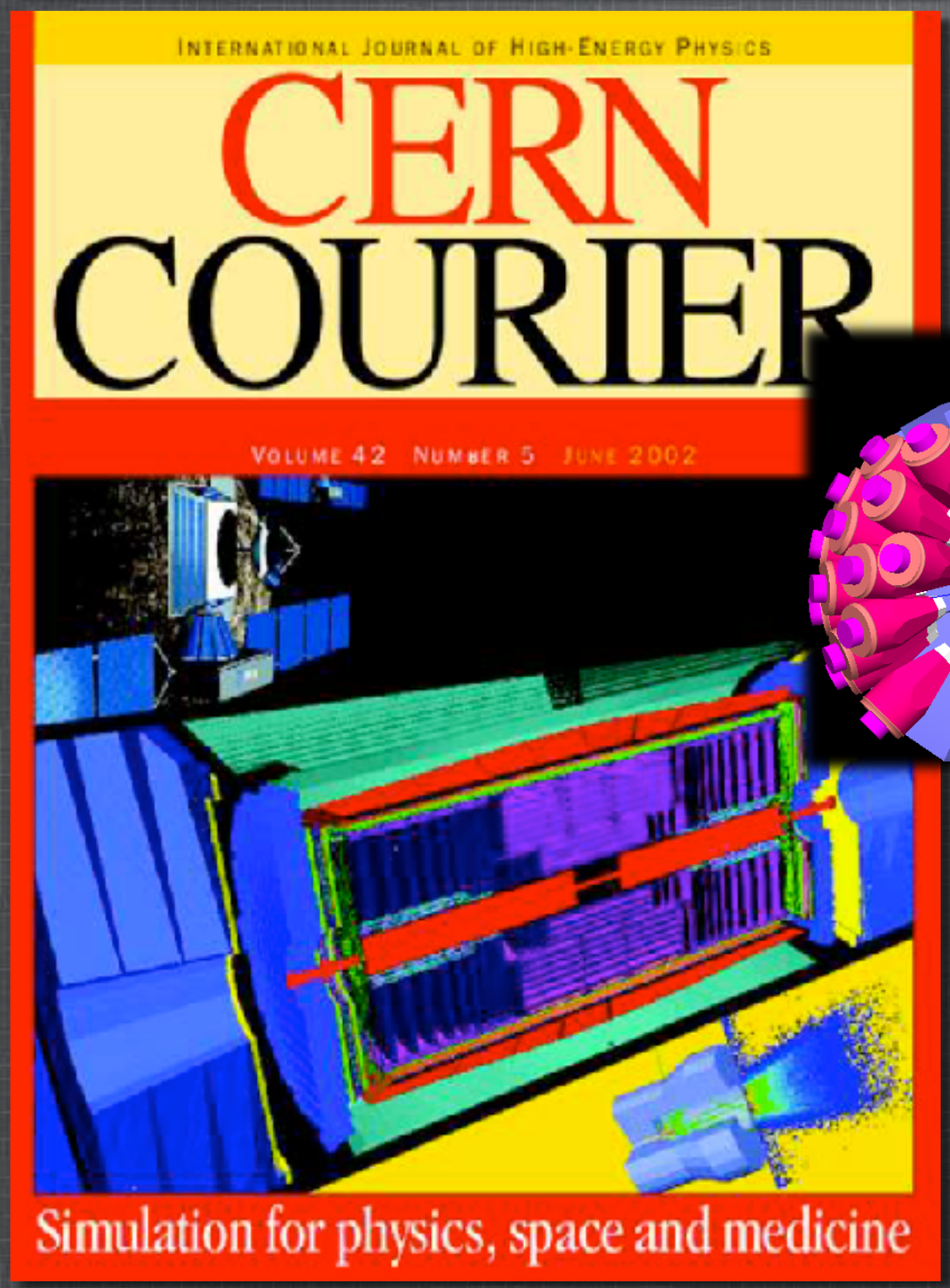
See more at this link

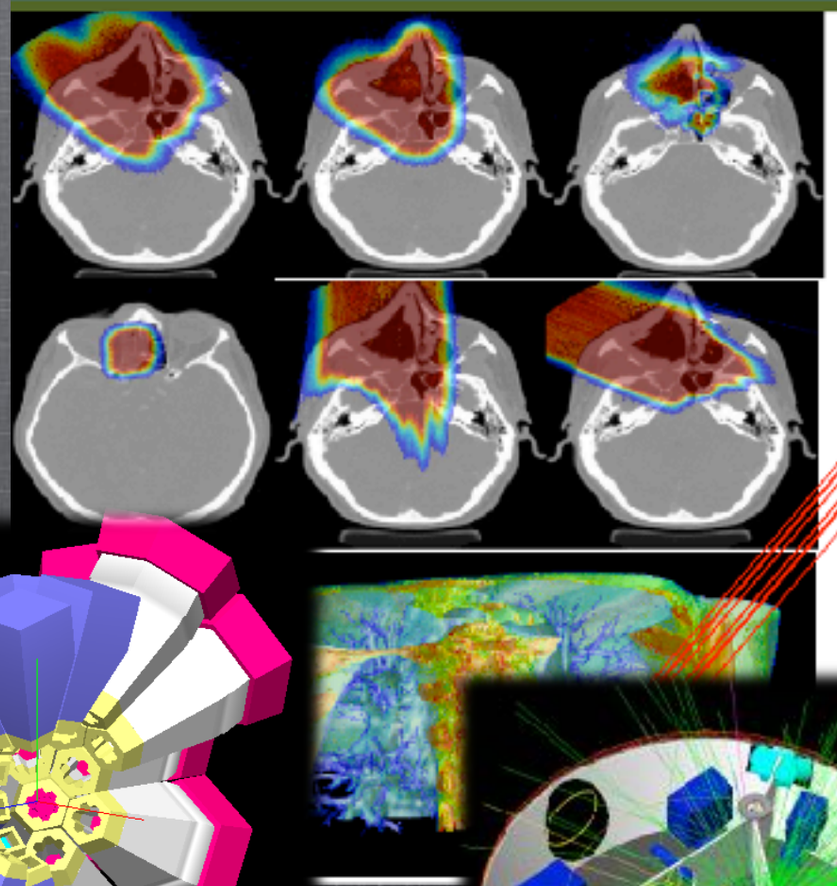
- Friday 23 November 2012 - Read

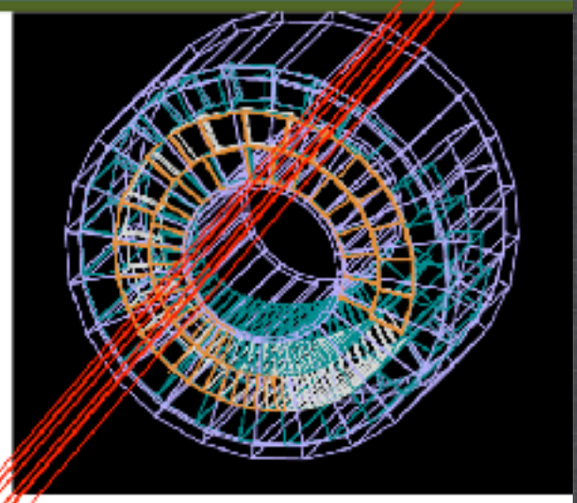
http://geant4.in2p3.fr

GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges

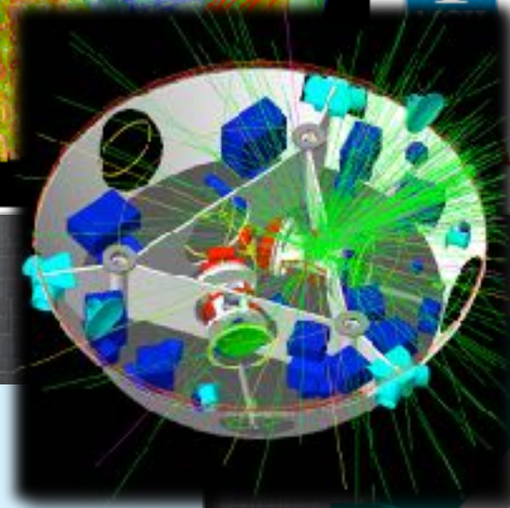


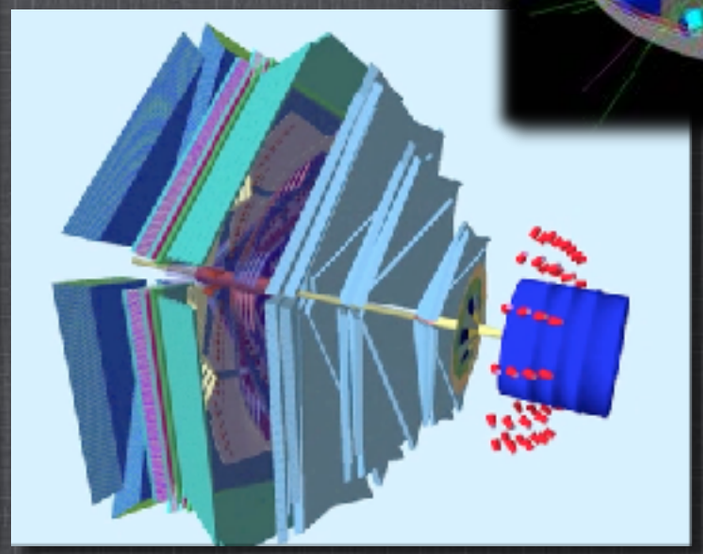


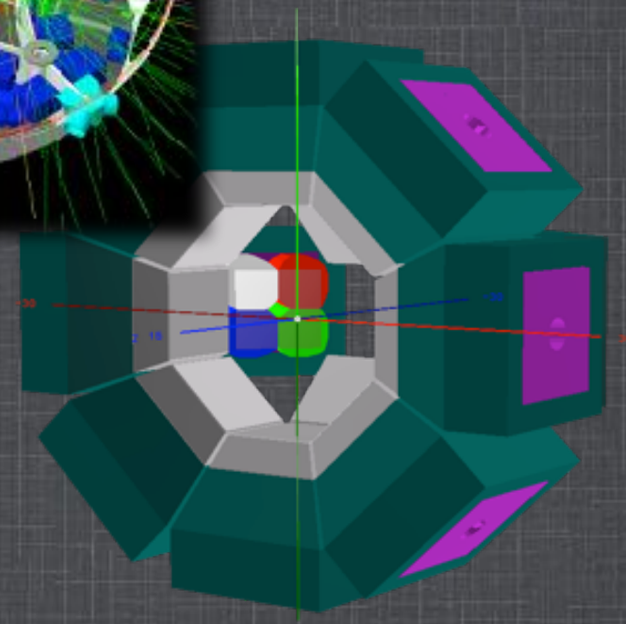




Harald Paganetti
MASSACHUSETTS GENERAL HOSPITAL
HARVARD MEDICAL SCHOOL







Some general statements

Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

What is It? Monte Carlo method ...

At least one uniform generator required [0,1[

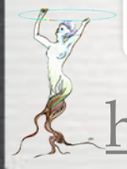
➥ the random engine produce pseudo-random numbers ...

TRandom	10^9	34 ns	**linear congruential** $X_{n+1} = (aX_n+C) \% m$
TRandom1	10^{171}	242 ns	RANLUX
TRandom2	10^{26}	37 ns	Tausworthe de l'Ecuyer
TRandom3	10^{6000}	45 ns	Mersenne Twister

+ initialization: **seed (reproducibility)** !

➥ according to your needs. **Do not run twice with same seed to add data** ...

With this one, more complex ones can be built ➢➢➢

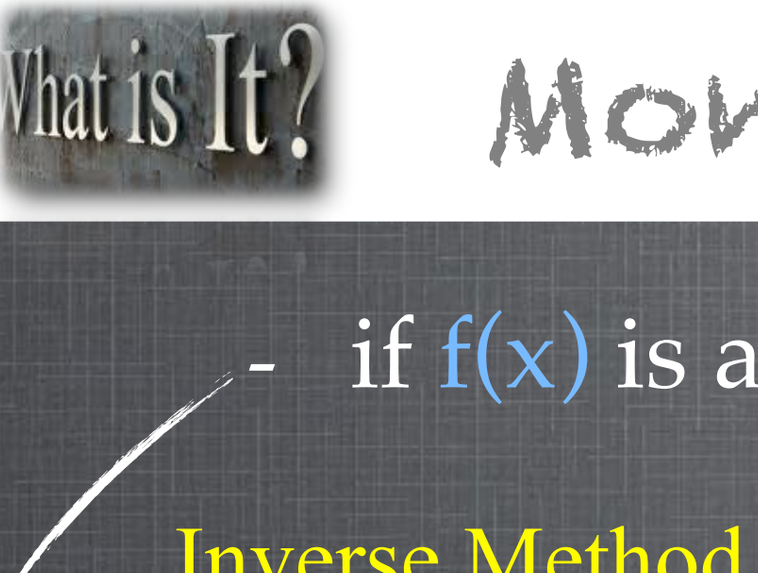


What is It? Monte Carlo method ...

- if f(x) is a probability density function -

Inverse Method

x uniform in [0,1[➪ $F^{-1}(x)$ is 'f(x) distributed'
F^{-1} ☛ F cumulative distribution function

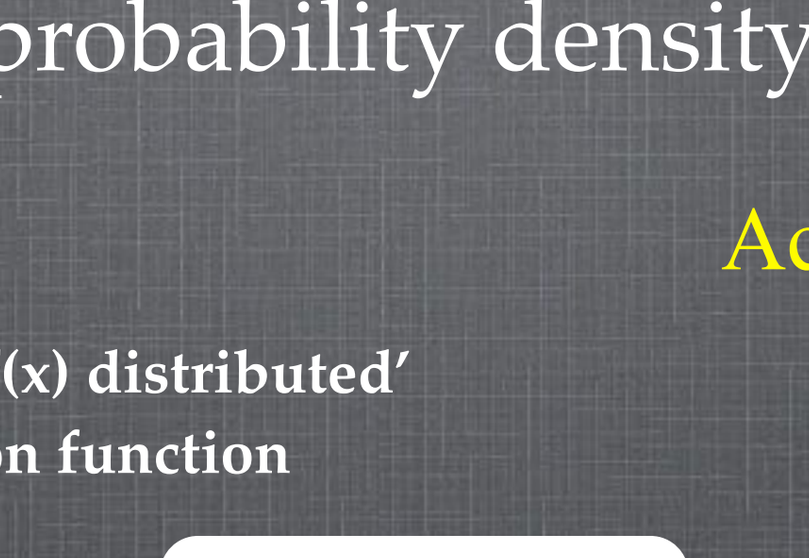


$$F(x) = \frac{\int^x f(u)du}{\int f(u)du}$$

Accept - Reject Method

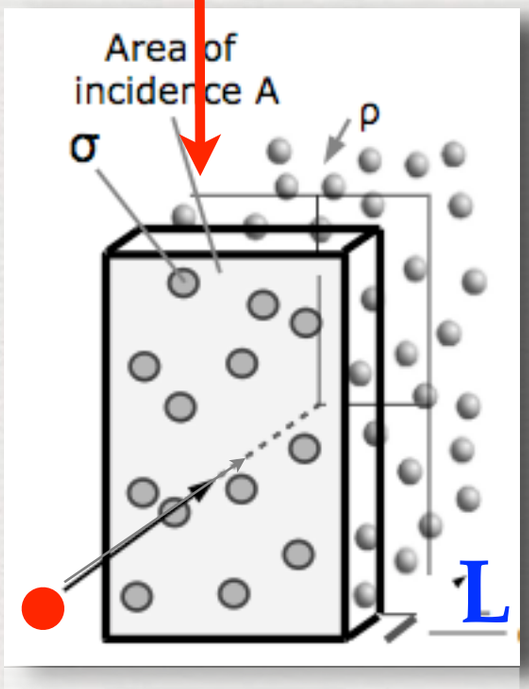
(x_i,y_i) uniform in ▭

accept x_i if $y_i < f(x_i)$
➥ x_i 'f(x) distributed' !



Monte Carlo method ...

One **particle** goes through **many others** (stopped)



- ➥ one cannot know where they are
- ➥ even if, it would cost a lot of computing power
- ➥ Quantum mechanism: interactions are probabilistic !
- ➥ statistical methods ...

Hypothesis :

Nuclei are uniformly distributed

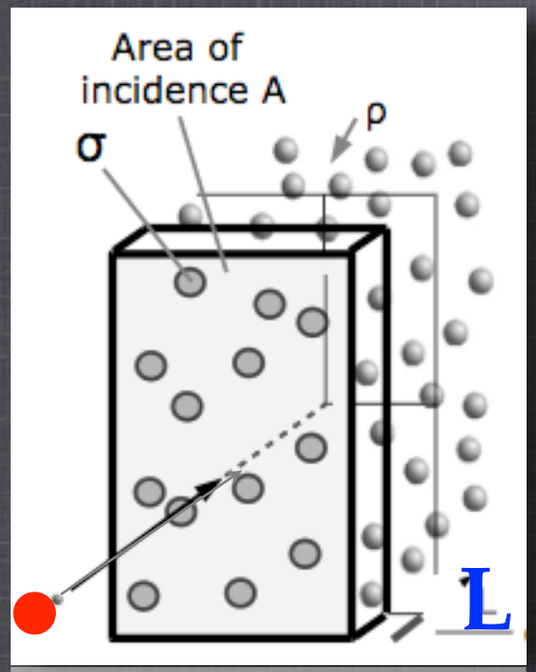
Probability for the **particle** to travel undisturbed for a distance **L** ?

$$I_{\varnothing}(L) = \frac{\text{Number of particles reaching } \mathbf{L} \text{ without 'interaction'}}{\text{Number of particles shot}}$$

- ☛ **scattering**
- ☛ **decay**

frequentist's approach

What is It? Monte Carlo method ...



After playing a bit ➠ $I_{\varnothing}(L) = \exp(-\varrho.L.\sigma)$

$\varrho^{macroscopic}$ density of matters

$\sigma^{microscopic}$ cross section of the interaction process

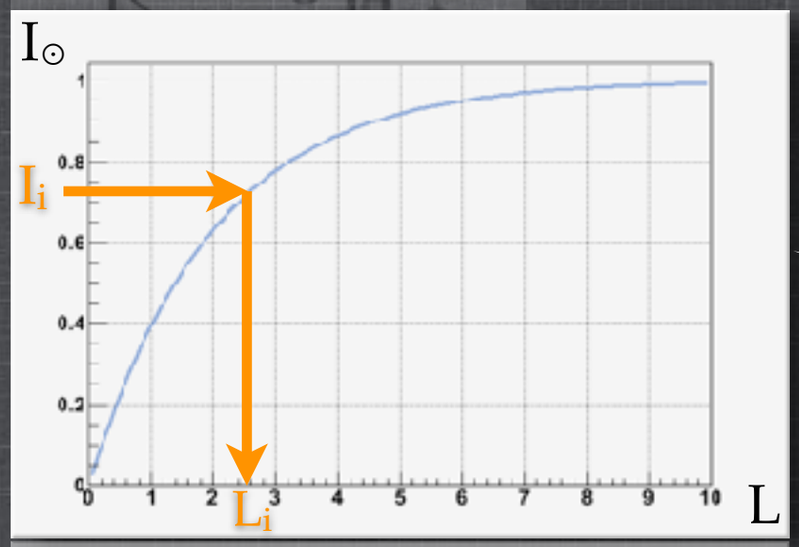
σ (type particle, energy, ...) - ex : $\sigma = \pi r^2$

➥ it relies on models, measurements (database)

Probability to have an interaction at L :

➠ $I_{\odot}(L) = 1\text{-}I_{\varnothing}(L) = 1\text{-}\exp(-L/\lambda)$

where λ(type ...) is the mean free path length



to simulate one shot,
select randomly I_i ☛ L_i

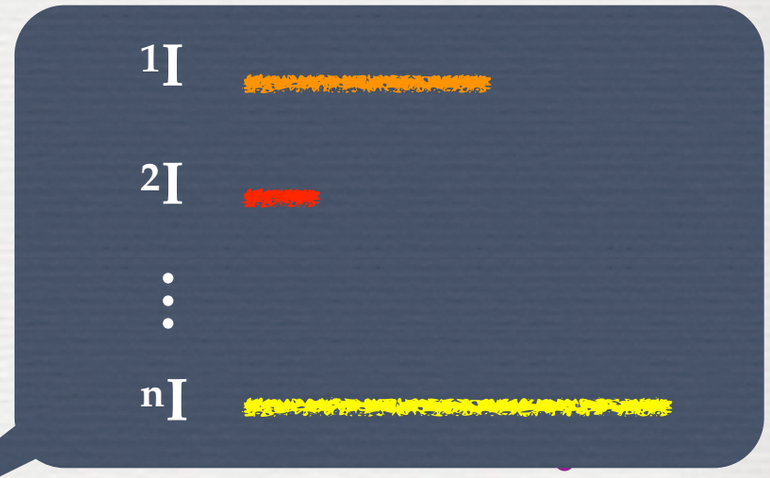
What is It? Monte Carlo method ...

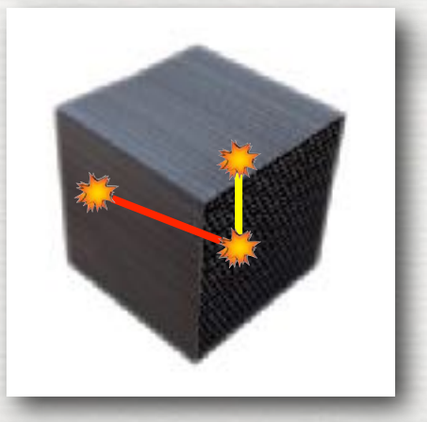
General case: competition between several processes ^{i}I

$^{i}I_{\odot}$ the probability of having an interaction at distance L

Core of the Monte Carlo Method !

- start values for incident particle
- get value for ϱ, σ
- sample L_i from $^{i}I_{\odot}$
- smallest L_s selects the process ^{s}I
- transport particle undisturbed by L_s
- simulate **interaction**



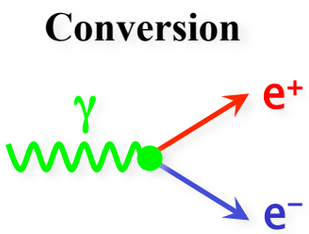


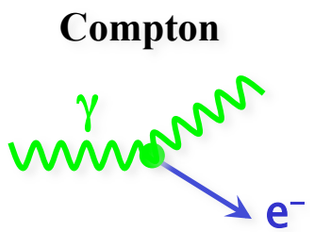
➥ secondary particles

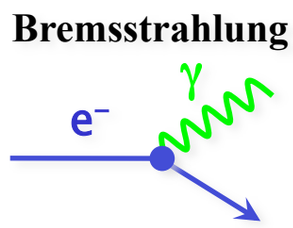
What is It? A quick overview of processes in G4

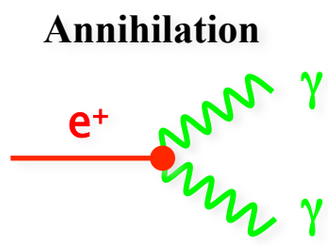
Electromagnetic, hadronic, optical, transport, decay ...

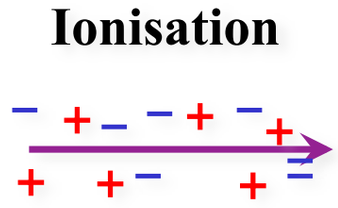
(based on models and/or databases-measurements ... expandable !)

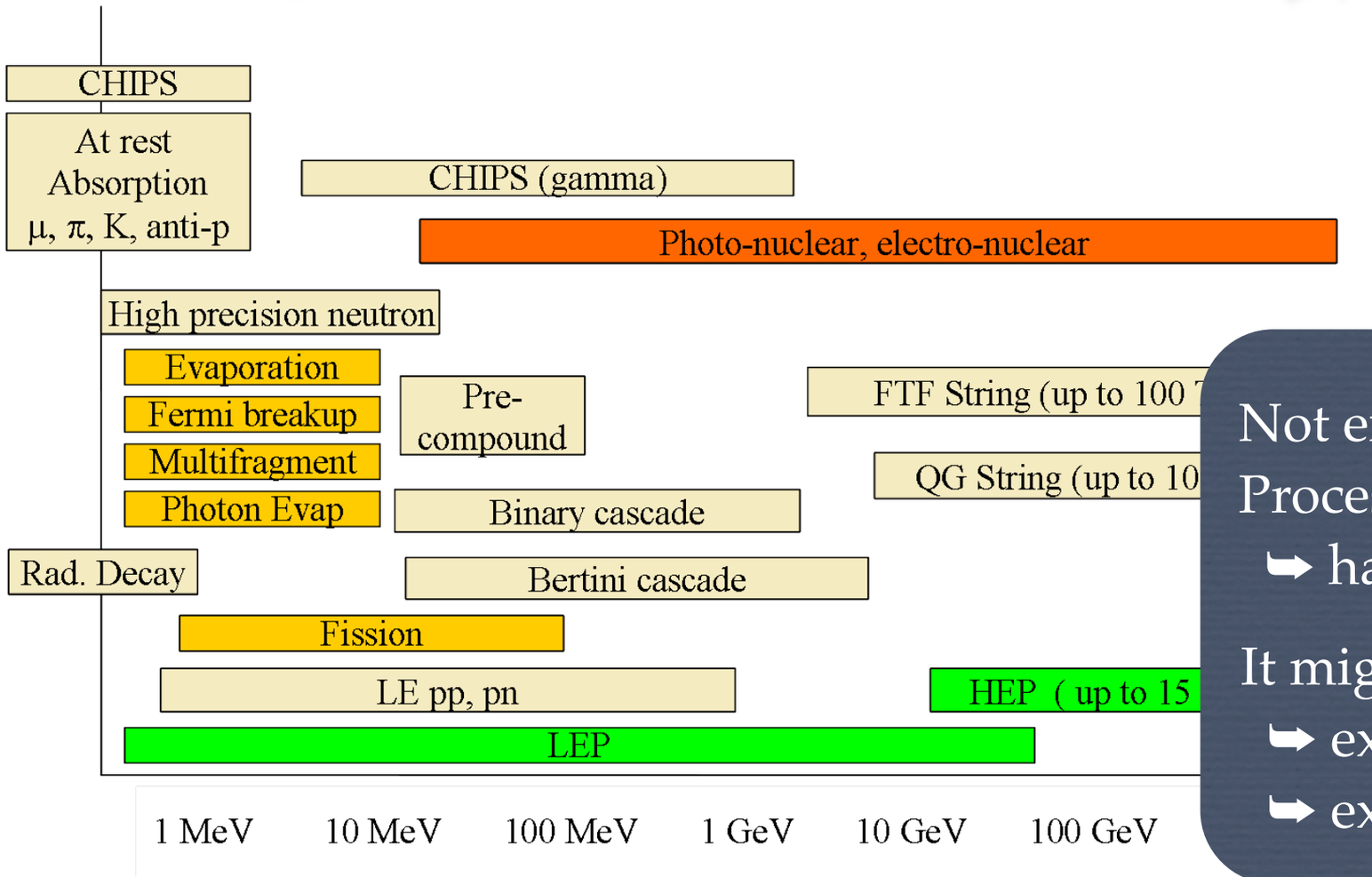












Not exhaustive! ... a lot of physics!

Processes in game:

➥ have to be set by users.

It might not be suitable for you !

➥ extension possible

➥ external inputs

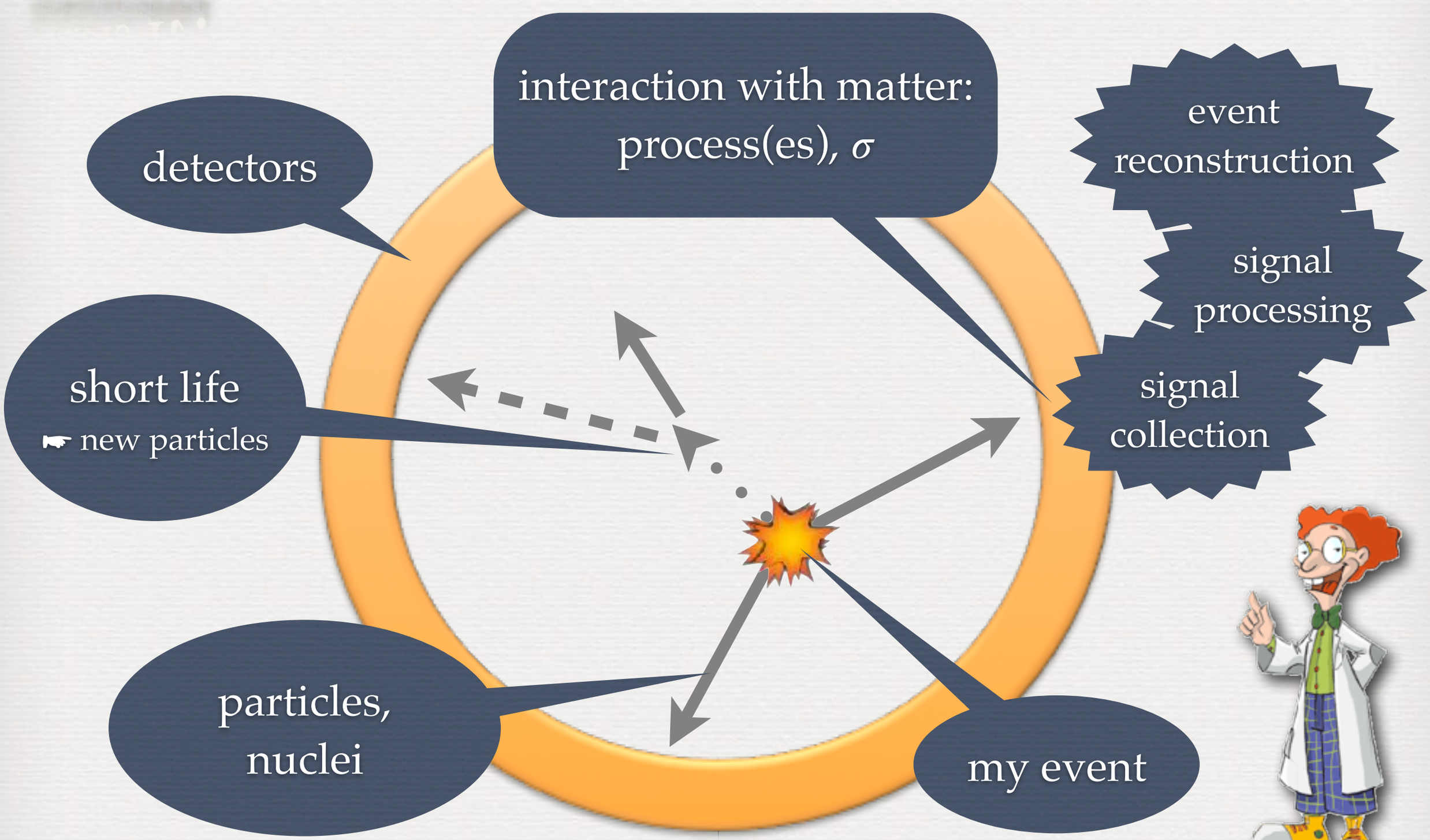
Some general statements

Monte Carlo into the *game*

Geant4 some vocabulary

The Geant4 machine

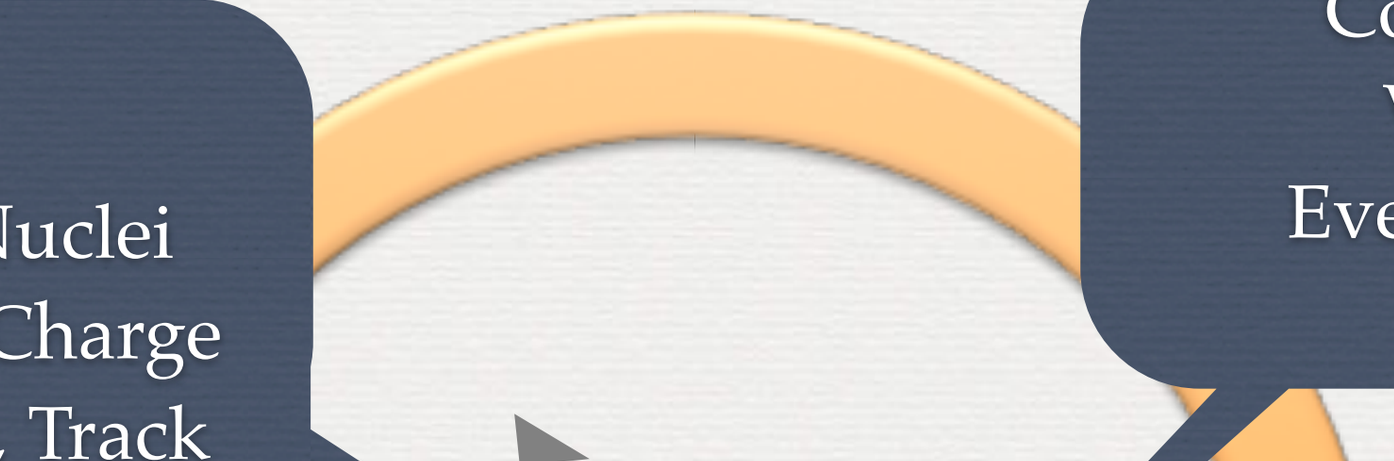
What is It? the world to be modeled



What is It? the world to be modeled

Particles, Nuclei
Mass, Spin, Charge
Momentum, Track
Decay products
...

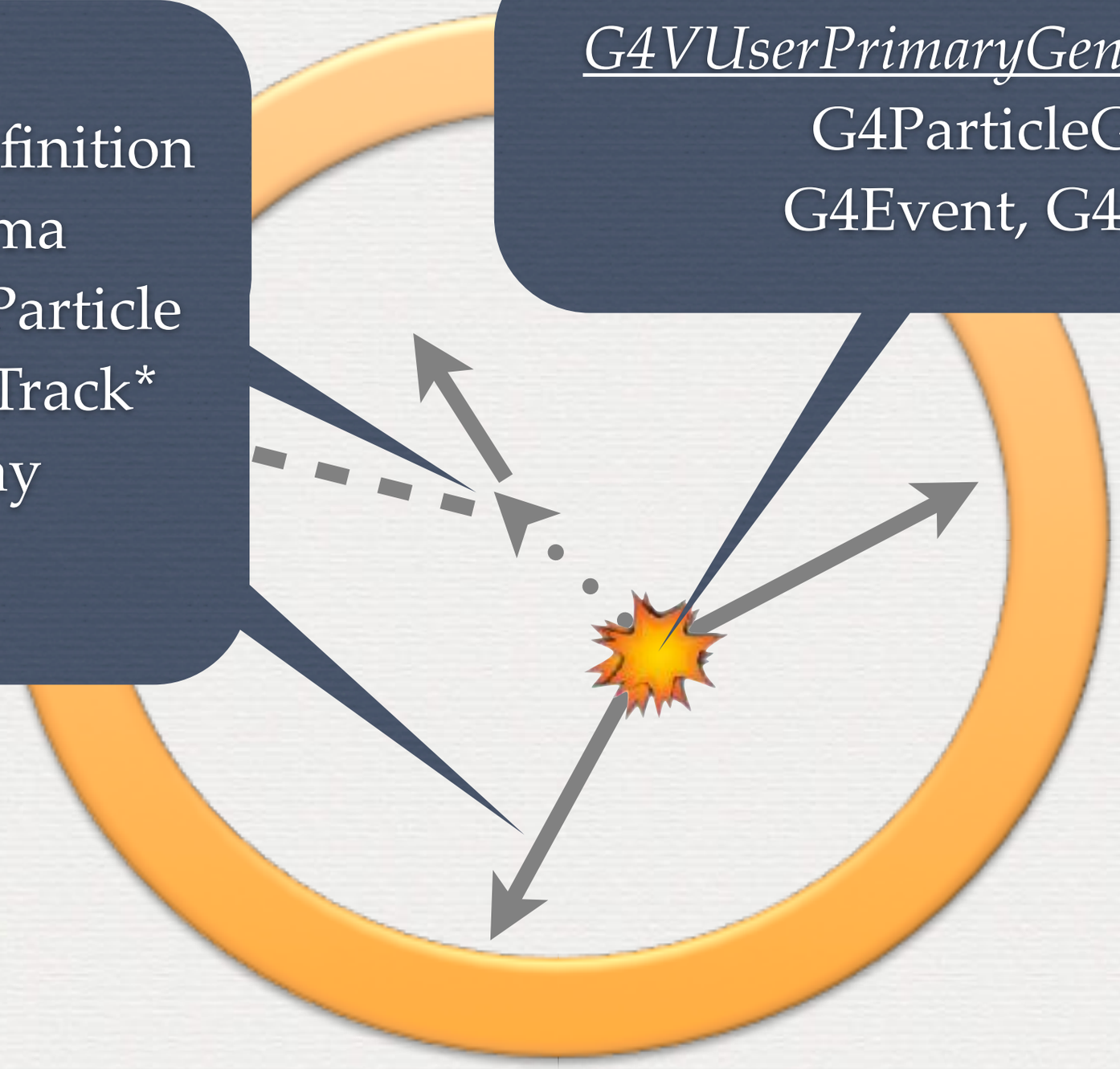
Collisions
Vertex
Events, Run
...



What is It? the GEANT4 [G4] world

G4VUserPrimaryGeneratorAction
G4ParticleGun
G4Event, G4Run

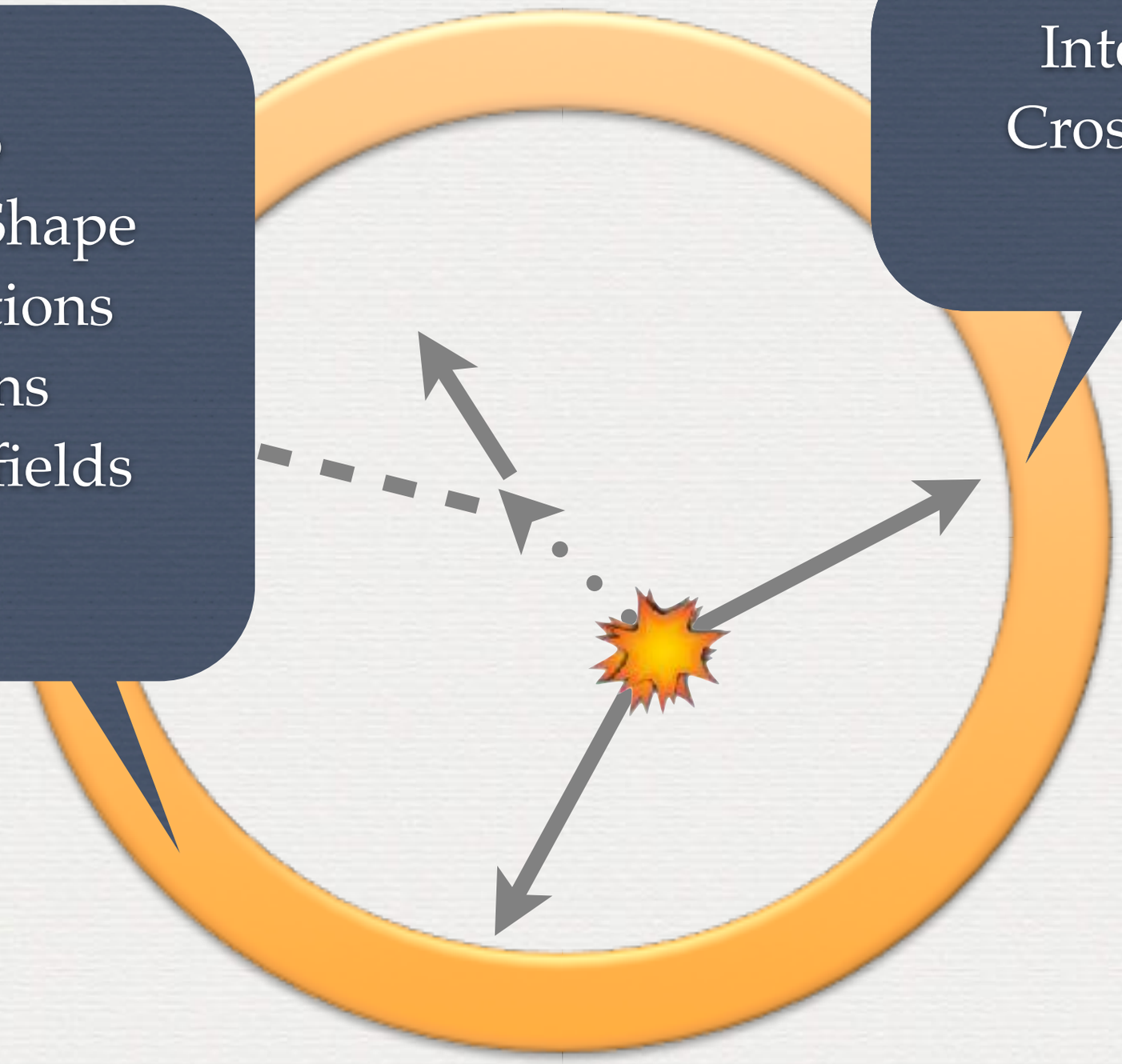
G4ParticleDefinition
G4Gamma
G4DynamicParticle
G4Step, G4Track*
G4Decay
...



*** a G4Track is not a collection of G4Step but a snapshot of a particle within its environment**

What is It? the world to be modeled

Setup
Material, Shape
Compositions
Positions
Magnetic fields
...



Interactions
Cross Sections
...

What is It? the GEANT4 [G4] world

G4VUserDetectorConstruction

G4Material, G4Solid

G4LogicalVolume,

G4VPhysicalVolume

G4ThreeVector, G4RotationMatrix

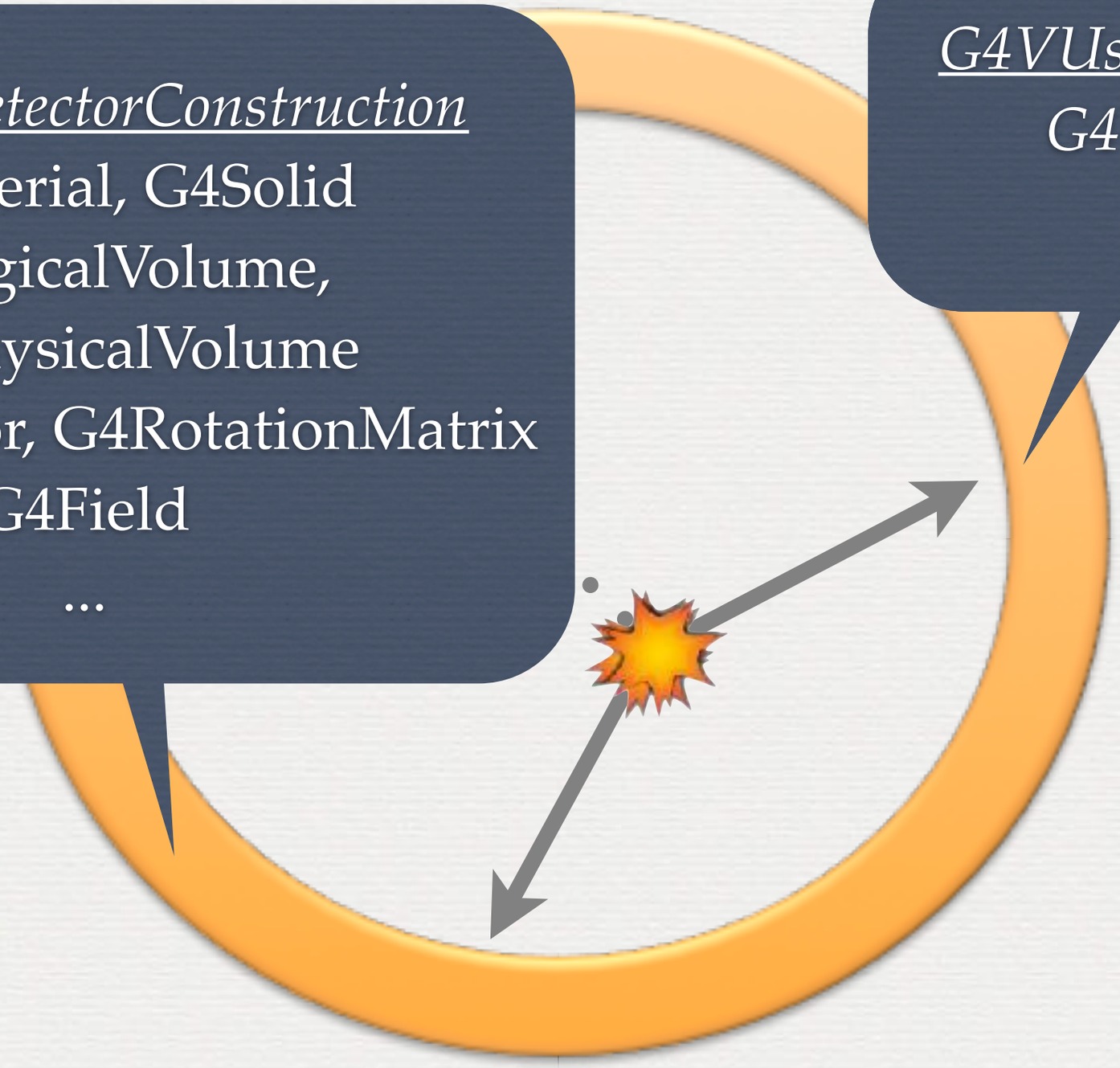
G4Field

...

G4VUserPhysicsList

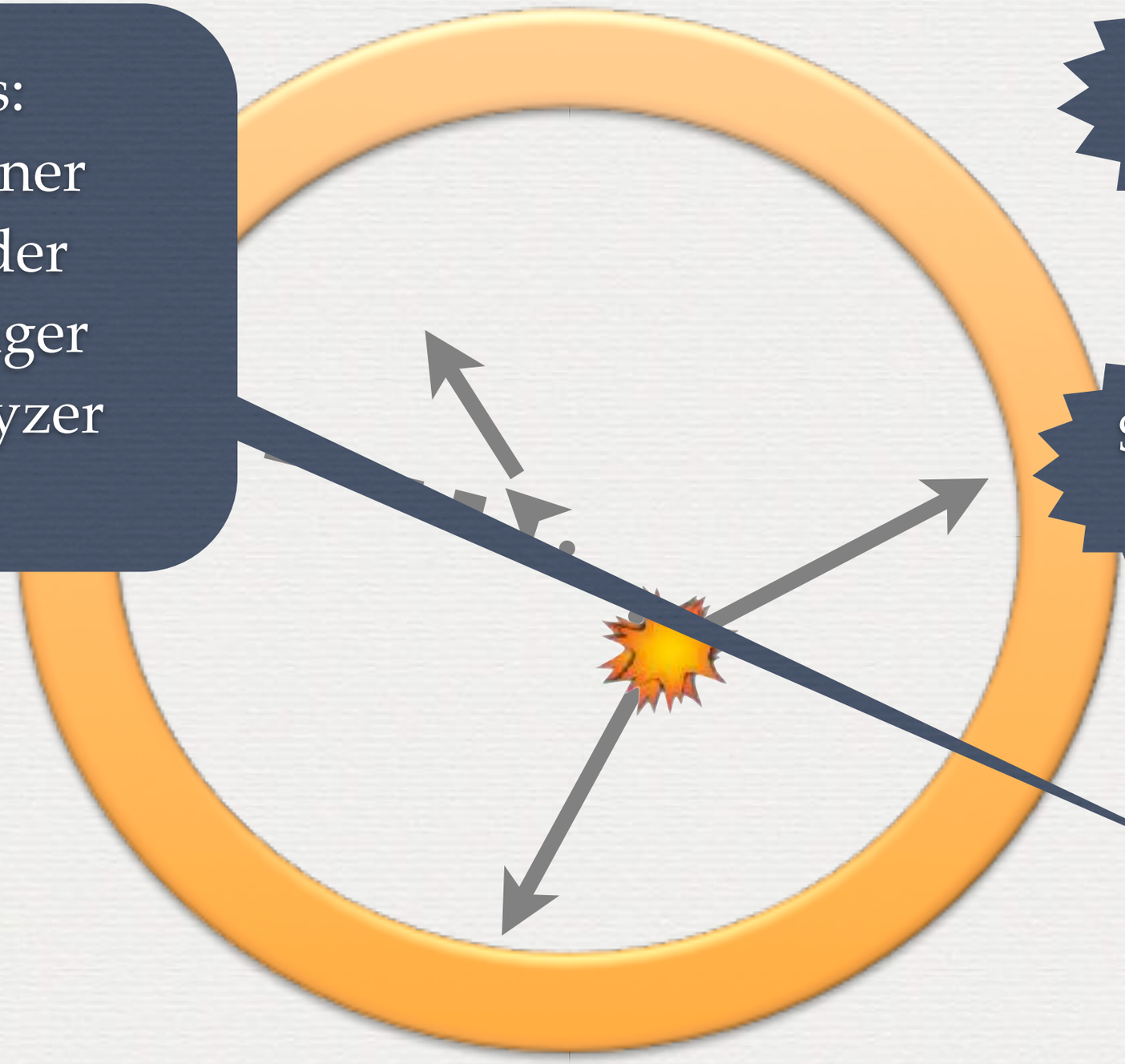
G4VProcess

...



What is It? the world to be modeled

He is:
a designer
a builder
a manager
an analyzer
...



Readout

Hits

Sensitive part

What is It? the GEANT4 [G4] world

G4 inner control

G4RunManager

G4EventManager

G4SteppingManager

G4TrackingManager

...

User's Actions

G4VUserRunAction

G4VUserEvenAction

...

G4VDigi

G4VHit

G4VSensitiveDetector

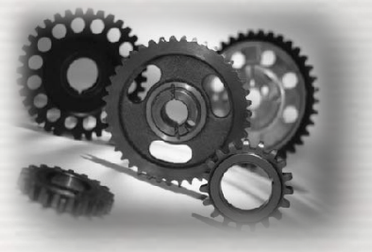
Some general statements

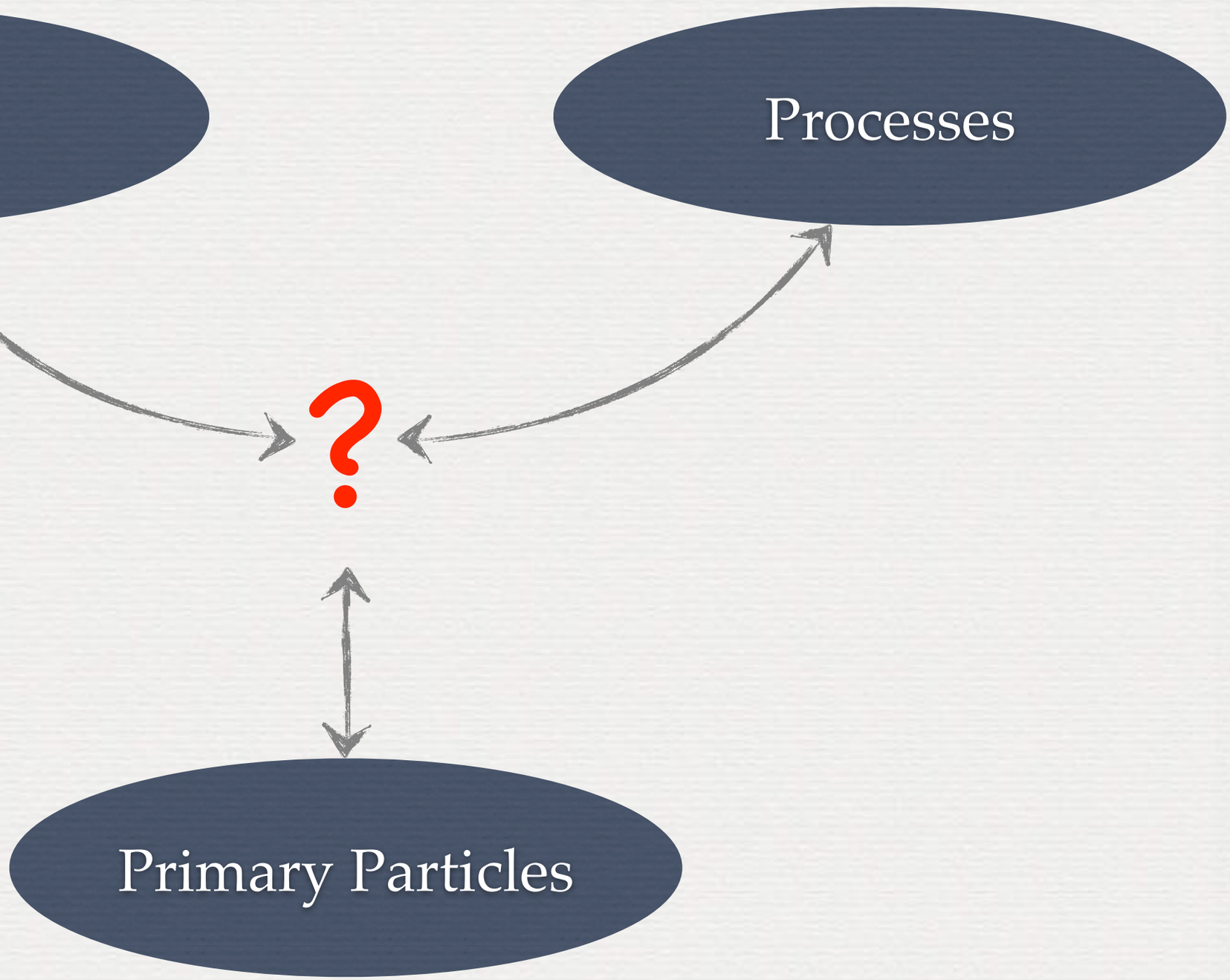
Monte Carlo into the *game*

Geant4 some vocabulary

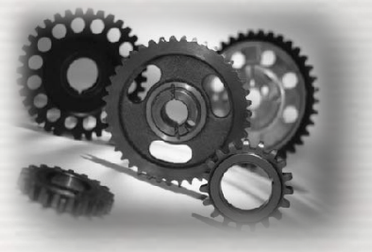
The Geant4 machine

All G4Things together





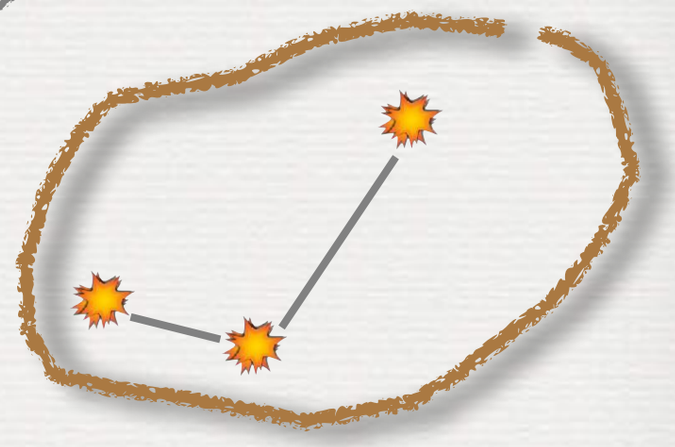
All G4Things together



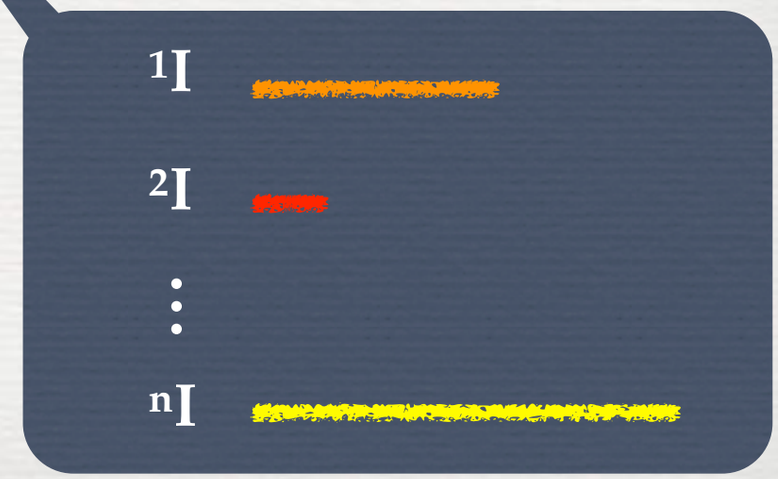
Detector

Processes

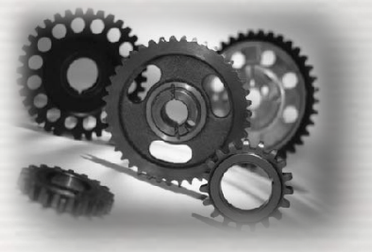
Stepping !!



Primary Particles



All G4Things together



```
public G4VUserDetectorConstruction
{
...
}
```

```
public G4VUserPhysicsList
{
...
}
```

```
public G4VUserPrimaryGeneratorAction
{
...
}
```

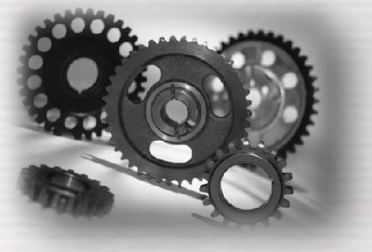
- First Phase, initialization:
  - ☑ Definition of the full setup
  - ☑ What particles, What processes they see
  - ☑ Primary generator in action
- Then Main loop :

/run/BeamOn 10000

- Start run # 1 : conditions of simulation fixed*
  - Start event # i
    primaries randomly generated and tracked
  - Stop event # i
- Stop run# 1 -

* geometry, processes

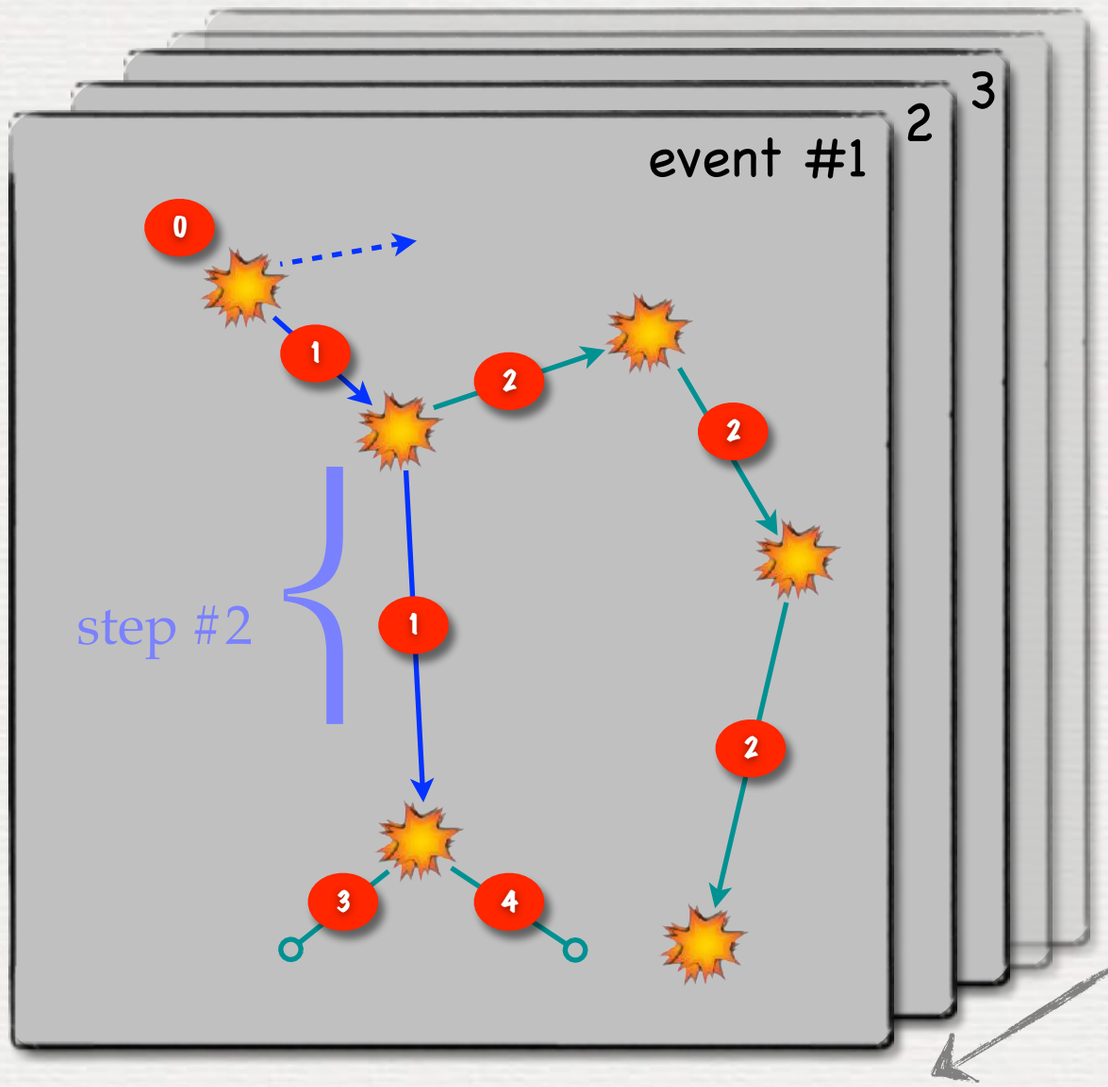
What is It? ALL G4Things together



'Loupe' on the main loop

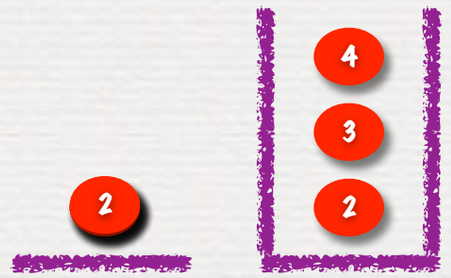
Start run # 1 :
  Start event # i
    Start track # j
      Start step # k

      Stop step # k
    Stop track # j
  Stop event # i
Stop run # 1

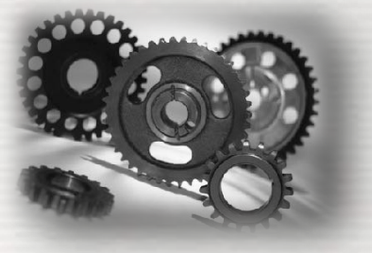


k Track ID

Track stack

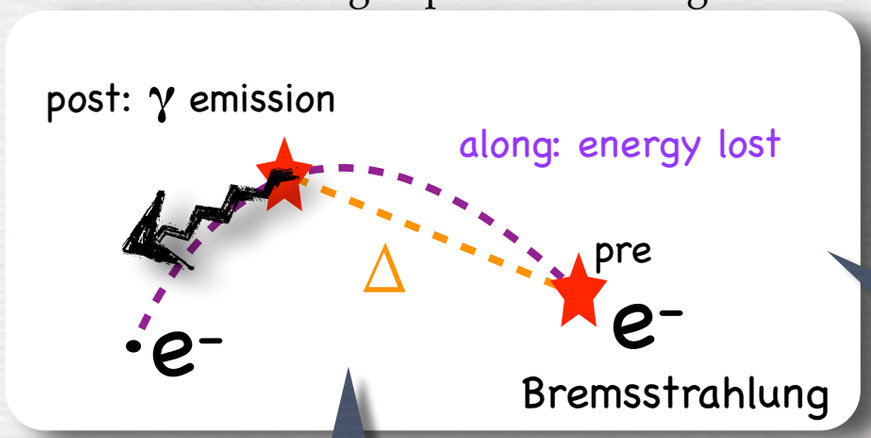


Some remarks about steps



- G4Step do not match necessarily the real trajectory

same remark for charged particles in magnetic fields



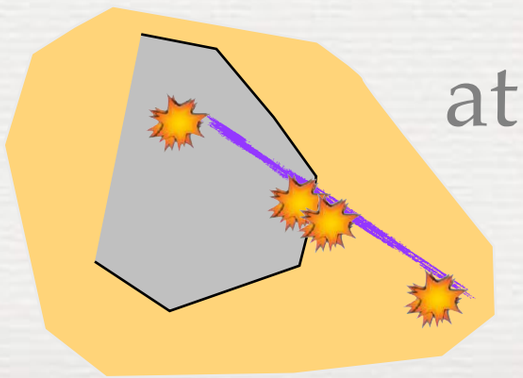
★ G4StepPoint: one Pre, one Post

Δ G4Step: store delta information

in G4, distinctions between: Along, PostStep, AtRest processes

once a process is selected:
❶ all AlongStep are applied
❷ PostStep of the selected

- Fictive G4Step introduced at boundaries



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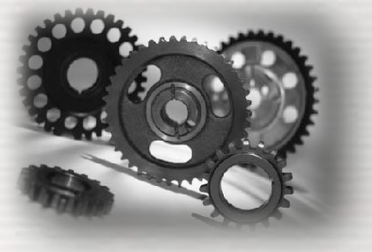
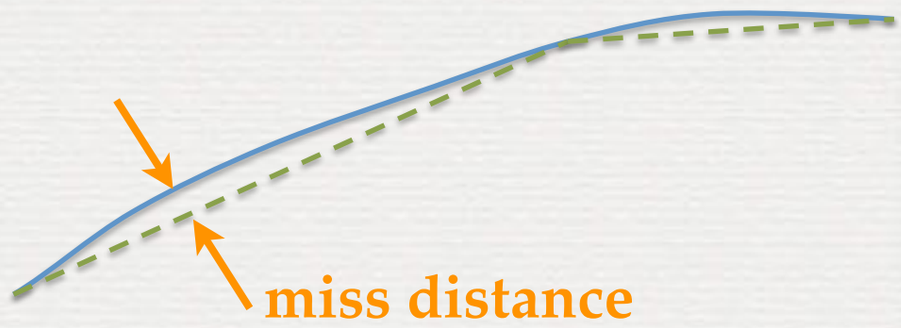


- In order to propagate **a particle inside a magnetic and/or electric field**, the equation of motion of the particle in the field is solved

- The *Runge-Kutta* method for the integration of the ordinary differential equations of motion

- In specific cases other solvers can also be used:
  - *In a uniform field, using the analytical solution*
  - *In a nearly uniform field (BgsTransportation)*
  - *In a smooth but varying field, with new RK+helix*

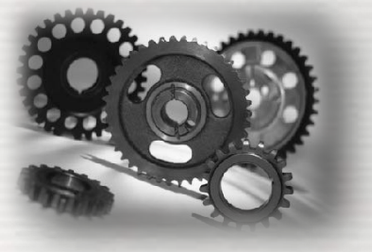


- Knowing the **trajectory**, G4 breaks up this curved path into **linear chord segments**
  - The chord segments are chosen so that they closely approximate the curved path
  - The chords are used to interrogate the Navigator, to see whether the track has crossed a volume boundary
  - The accuracy is controlled using a parameter called the '**miss distance**': it is a **measure of the error** in whether **the approximate track intersects a volume**

default 3mm

to be adapted for your physics ...

Some remarks about steps



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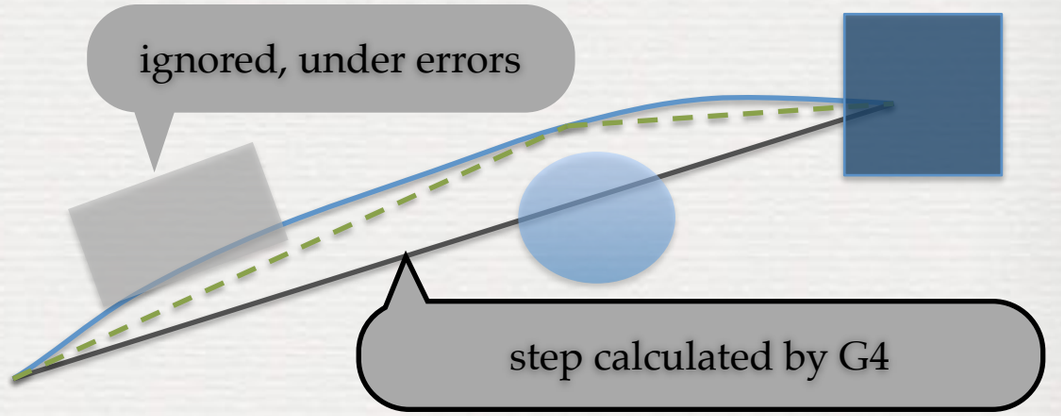

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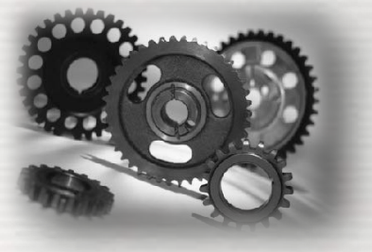

Geant4 introduces 'cuts'

- To avoid infrared divergence for electromagnetic processes
  - for gammas, electrons and positrons
- It is a distance (1.0 mm) converted to energy for each material
- It is not a tracking cut (i.e. stop tracking if step < 1.0mm)
  - Geant4 tracks particle down to zero kinetic energy
- It is a energy threshold*
  - above: secondaries created
  - below: just energy loss
- It could be a global, per particle or per region parameter

*at which discrete energy loss is replaced by continuous loss ... up to zero ...

Conclusions / remarks

Why? because it helps a lot !

A C++ toolkit, based on Monte Carlo method to simulate particles interactions with matter

Second time this lecture is given

- ➥ feedbacks mandatory !

Geant4 version 10.0 is also there

- ➥ running several CPU / cores in //
- ➥ more tricky to handle ...

The roadmap of the week

W1: installation / running a G4 application

W2: Primary generator, GPS, physics list

W3: Geometries

W4: Sensitive detectors / user's actions

Do the one
you want to practice on

NOW, HOW does it really work ?