Bruno Mazoyer - LAL 2018

TES HEP

Trans European School of High Energy Physics

Trans-European School of High Energy Physics

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Example of building a detector with Geant4 (practical work)

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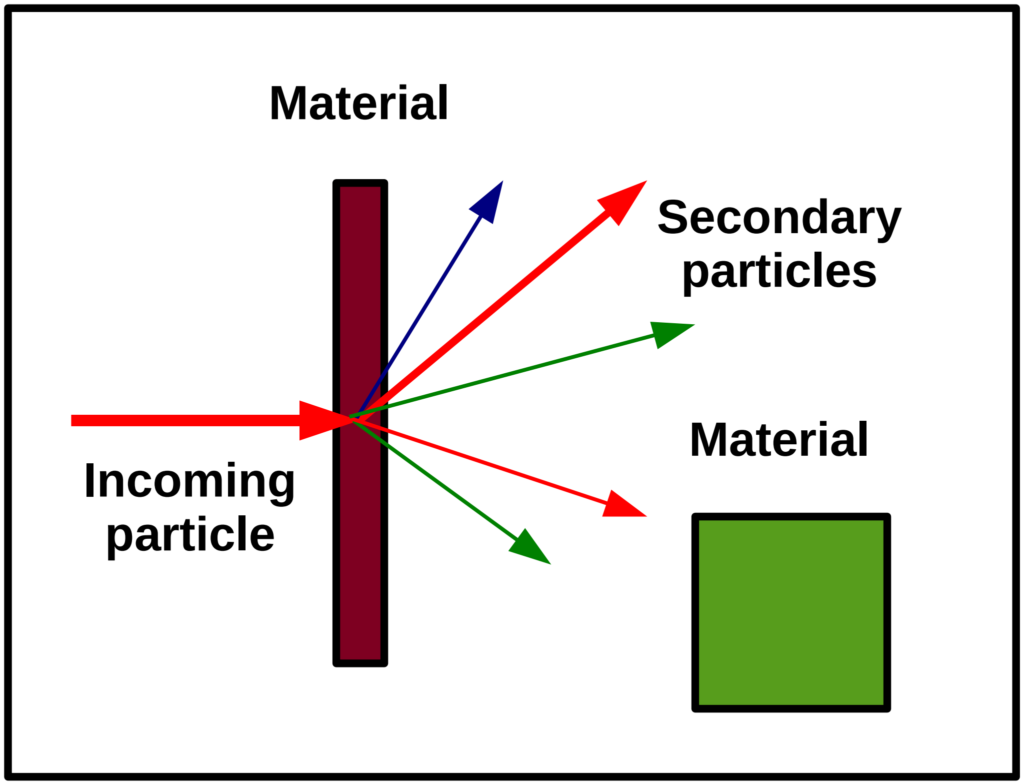


Geant4—a simulation toolkit

Geant4 is a toolkit for simulating the passage of particles through matter. It includes a complete range of functionality including tracking, geometry, physics models and hits. The physics processes offered cover a comprehensive range, including electromagnetic, hadronic and optical processes, a large set of long-livedparticles, materials and elements, over a wide energy range starting, in some cases, from 250eV and extending in others to the TeV energy range. It has been designed and constructed to expose the physics models utilised, to handle complex geometries, and to enable its easy adaptation for optimal use in different sets of applications. The toolkit is the result of a worldwide collaboration of physicists and software engineers. It has been created exploiting software engineering and object-oriented technology and implemented in the C++ programming language. It has been used in applications in particle physics, nuclear physics, accelerator design, space engineering and medical physics.

Nuclear Instruments and Methods in Physics Research A 506 (2003) 250–303

Geant4

- Geant4 is a toolkit for simulating the passage of particles through matter.

- It includes a complete range of functionality:
  - Tracking
  - Geometry
  - Physics models
  - Hits

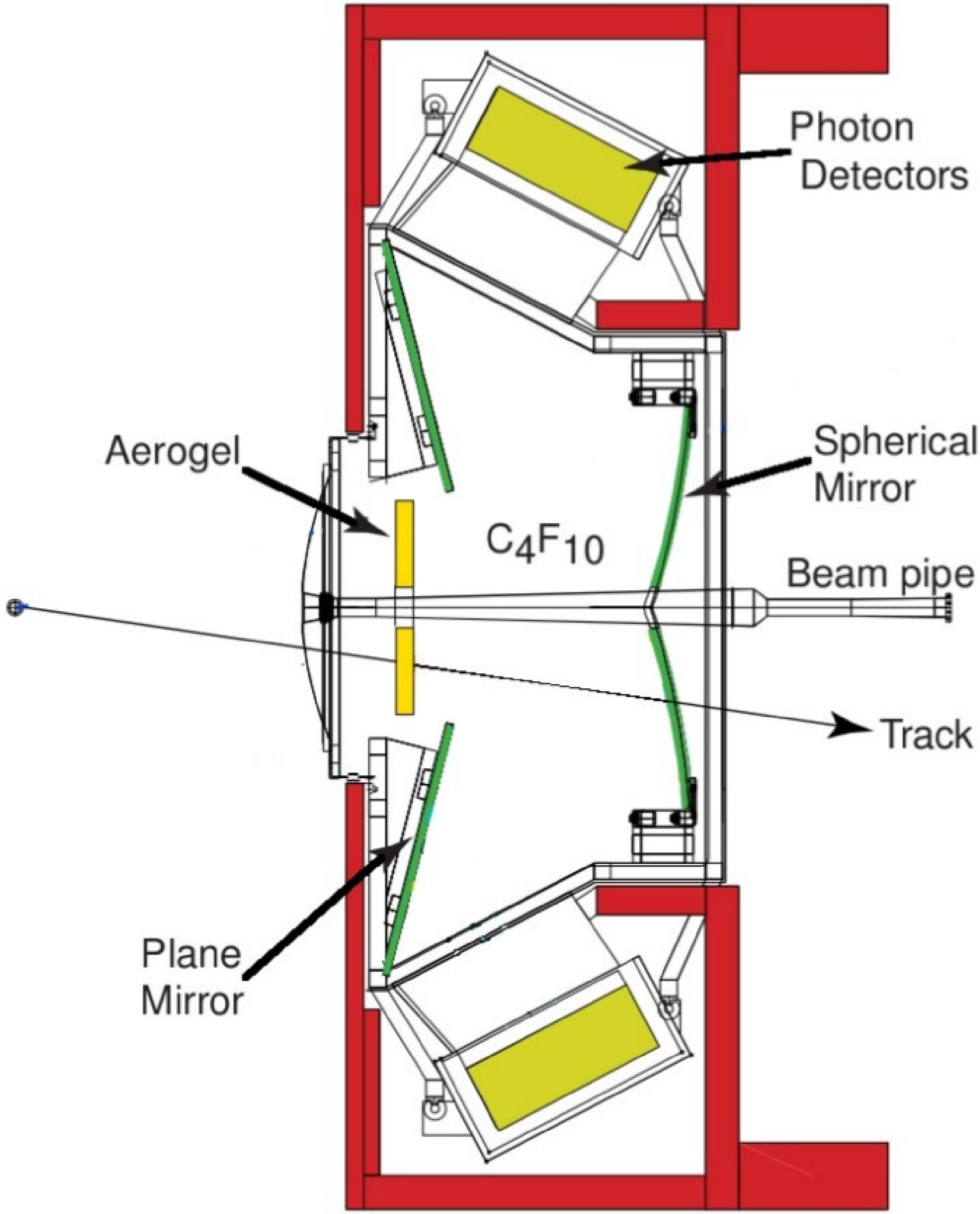
- The physics processes includes:
  - Electromagnetic
  - Hadronic
  - Optical

- Very wide energy range
  - Minimum : 250eV
  - Maximum : ~ TeV

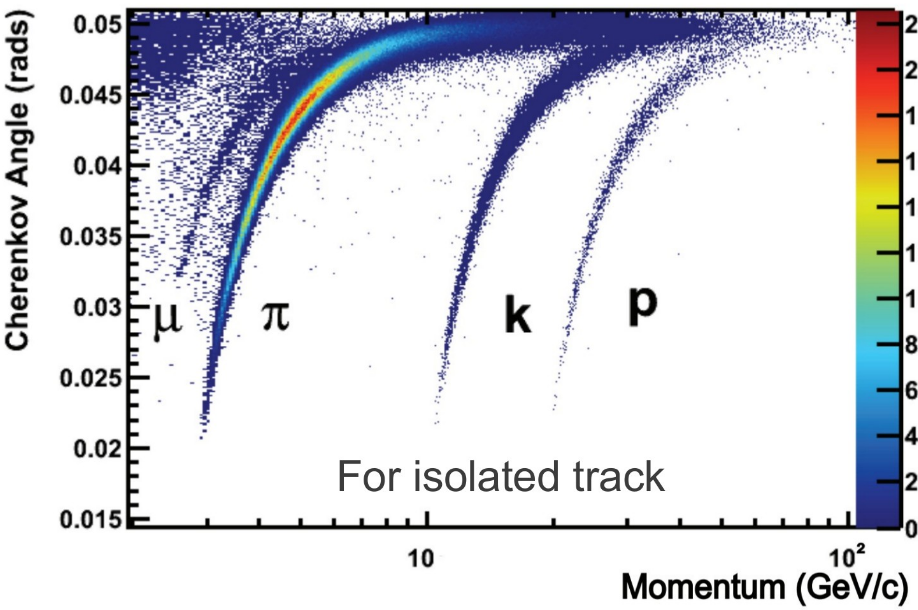
- Written in C++

LHCb-RICH1

RICH – Ring Image CHerenkov detector



RICH1



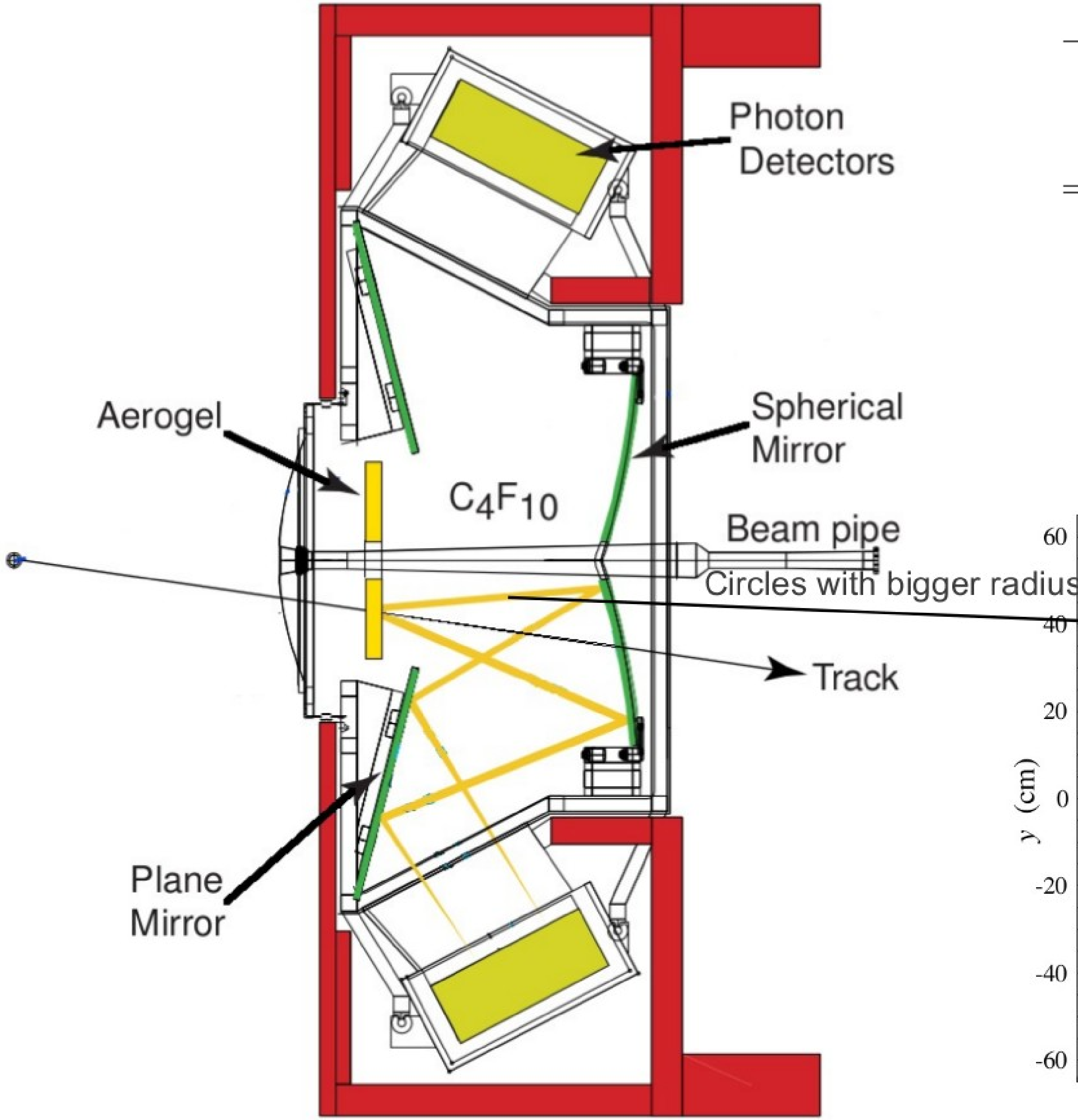
- Particle momentum reconstructed with tracker
- Using Cherenkov formula we can speed of the particle

$$\cos\theta_c = \frac{1}{n\beta}$$

- Mass of the particle can be defined since we have measure velocity and its momentum.

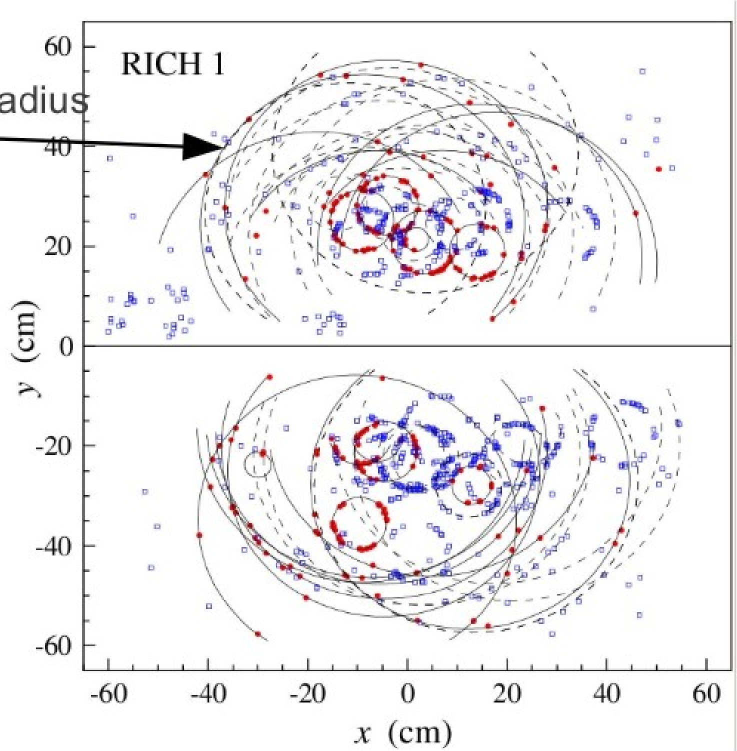
Geant4 first steps (practical work)

Cherenkov rings



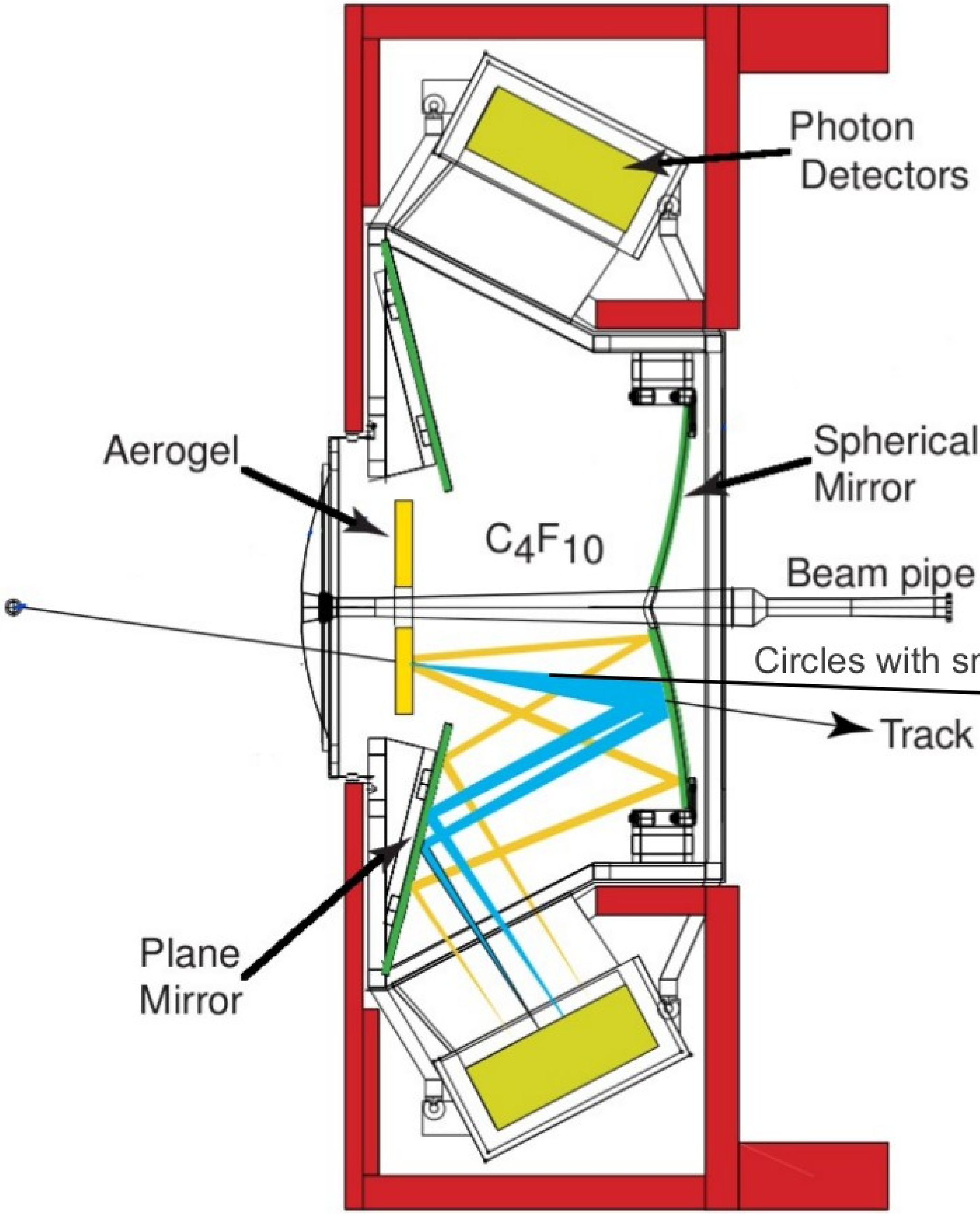
Material	C_4F_{10}	Aerogel
L[cm]	85	5
n	1.0014	1.03
$N_{p.e.}$	20.4	5.0

Aerogel for PID in momentum region from 1 to 20 GeV/c



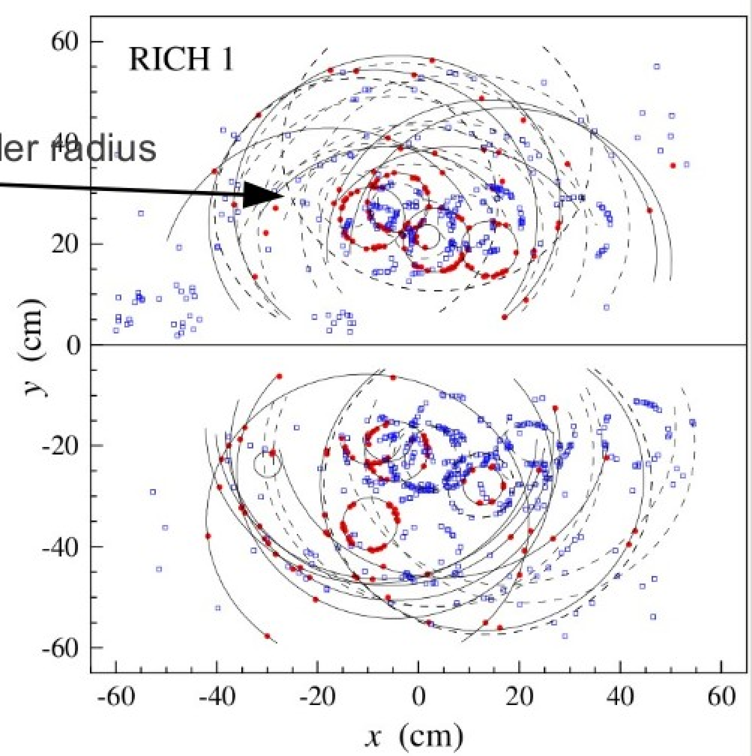
Cherenkov rings

Geant4 first steps (practical work)



Material	C_4F_{10}	Aerogel
L[cm]	85	5
n	1.0014	1.03
$N_{p.e.}$	20.4	5.0

C4F10 for PID in momentum region from 20 to 100 GeV/c



Geant4 simulation of the LHCb-RICH1

Geant4 program file description

lhcBrich.cc	→	**Main program**
DetectorConstruction.cc	→	Description of the materials and geometry of the experiment
PhysicsList.cc	→	Description of the physical processes
PrimaryGeneratorAction.cc	→	Definition of the primary particles
RunAction.cc	→	User actions before and after run
EventAction.cc	→	User actions before and after Evnet
SteppingAction.cc	→	User actions before and after step
SensitiveDetector.cc	→	User actions when sensitive detector has been hits by the particle
TrackingAction.cc	→	User action when new track has been created

vis.mac → *.mac file is interface file for Geant4 simulation program. Usually name vis.mac emphasize that it is for visualization (geometry only or couple of events).

run.mac → File run.mac set variables for hight statistic simulation (many events)

Command reminder

→ cd TESHEP2018	Enter the main directory
→ source setup.bash	Setup working space
→ cd lhcBrich-build/	Working directory of G4 ex.
→ cmakegeant ../lhcBrich	Setup the example
→ make	make example
→ ./lhcBrich vis.mac 23142 lhcBrich.root proton 100 10 90	Run the example
→ hepvis G4Data0.heprep	Visualization
→ cd ../anaLhcBrich	Directory for root analysis
→ root -l mainAna.C	Run root analysis

STEPS

1) Enter your working directory : TESHEP2018 and setup the working space :

> cd TESHEP2018
> . setup.bash

```
Check if the files/folders are there
ls /home/leonid/root_v5.34.34/root_v5.34.34-install/bin/thisroot.sh
/home/leonid/root_v5.34.34/root_v5.34.34-install/bin/thisroot.sh
ls /home/leonid/geant4.10.02.p01/geant4.10.02.p01-install/share/Geant4-10.2.1/geant4make/geant4make.sh
/home/leonid/geant4.10.02.p01/geant4.10.02.p01-install/share/Geant4-10.2.1/geant4make/geant4make.sh
ls /home/leonid/geant4.10.02.p01/geant4.10.02.p01-install/lib/Geant4-10.2.1/
Geant4Config.cmake        Geant4LibraryDepends.cmake                Linux-g++  UseGeant4.cmake
Geant4ConfigVersion.cmake  Geant4LibraryDepends-relwithdebinfo.cmake  Modules
ls /home/leonid/home2/TESHEP/TESHEP2018/
anaLhcBrich  HepRApp.jar  jre1.6.0_26  jre-6u26-linux-x64.bin  lhcBrich  setup.bash  TESHEP_Geant4_training_presentation_2018.odp
ls /home/leonid/home2/TESHEP/TESHEP2018//jre1.6.0_26/bin/java
/home/leonid/home2/TESHEP/TESHEP2018//jre1.6.0_26/bin/java
ls /home/leonid/home2/TESHEP/TESHEP2018/HepRApp.jar
/home/leonid/home2/TESHEP/TESHEP2018/HepRApp.jar
-----------------------------------

Check if the environment variables are defined
/home/leonid/root_v5.34.34/root_v5.34.34-install
/home/leonid/geant4.10.02.p01/geant4.10.02.p01-install/share/Geant4-10.2.1/geant4make
cmake version 3.5.1

CMake suite maintained and supported by Kitware (kitware.com/cmake).
-----------------------------------

Check alias
alias cmakegeant='cmake -DGeant4_DIR=/home/leonid/geant4.10.02.p01/geant4.10.02.p01-install/lib/Geant4-10.2.1/'
alias hepvis='/home/leonid/home2/TESHEP/TESHEP2018//jre1.6.0_26/bin/java -jar /home/leonid/home2/TESHEP/TESHEP2018/HepRApp.jar'
-----------------------------------
```

2) Read carefully the output and check for errors

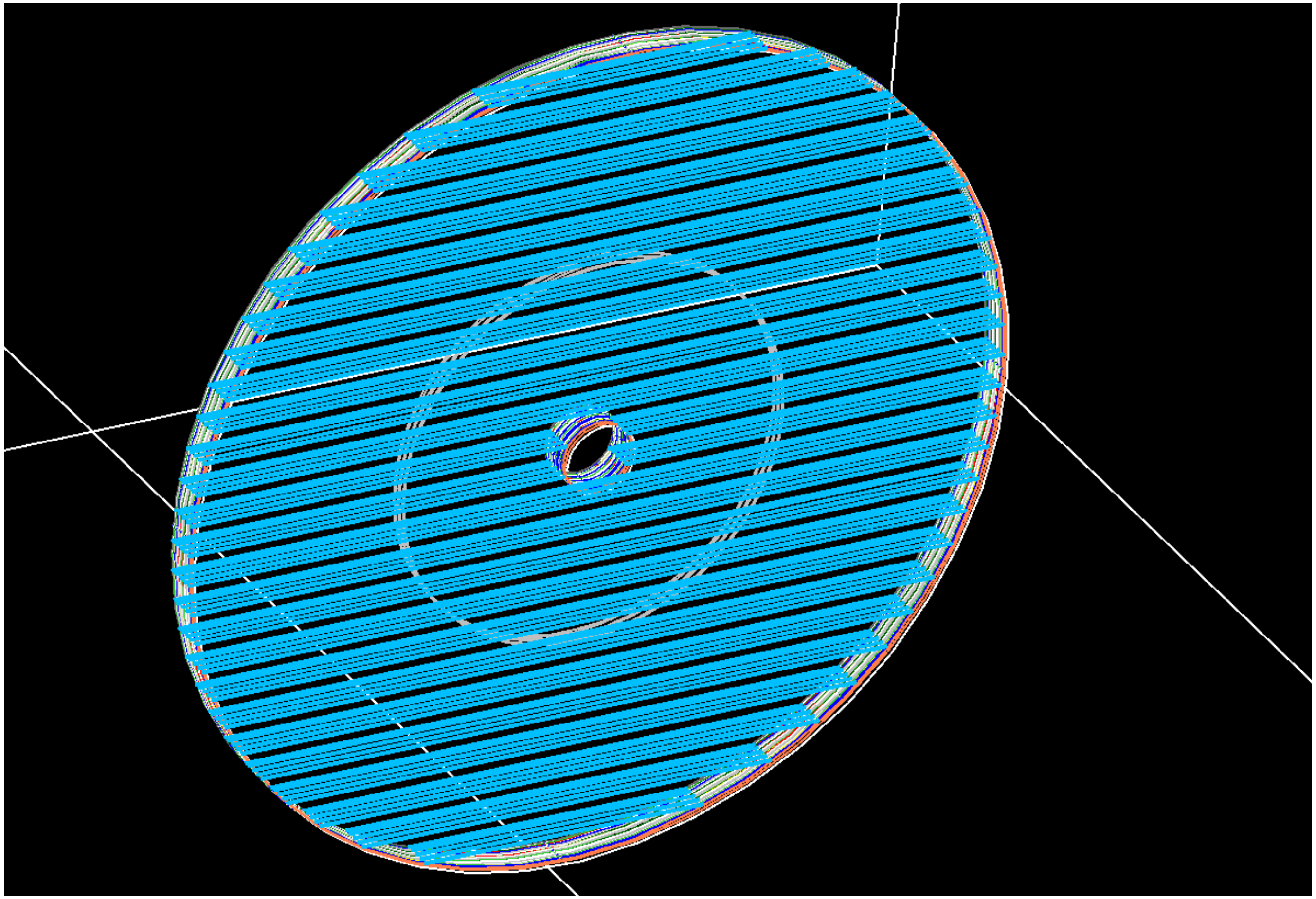
STEPS

3.1) Check if Geant4 is installed :
> printenv | grep G4

```
G4LEVELGAMMADATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/PhotonEvaporation2.2
G4INSTALL=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/geant4make
G4INCLUDE=/home/leonid/ProgFiles/geant4.9.5-build/include/Geant4
G4NEUTRONXSDATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/G4NEUTRONXS1.1
G4LEDATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/G4EMLOW6.23
G4NEUTRONHPDATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/G4NDL4.0
G4RADIOACTIVEDATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/RadioactiveDecay3.4
G4ABLADATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/G4ABLA3.0
G4LIB_USE_GDML=1
G4LIB=/home/leonid/ProgFiles/geant4.9.5-build/lib/Geant4-9.5.0
G4PIIDATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/G4PII1.3
G4LIB_BUILD_SHARED=1
G4UI_USE_TCSH=1
G4REALSURFACEDATA=/home/leonid/ProgFiles/geant4.9.5-build/share/Geant4-9.5.0/data/RealSurface1.0
G4SYSTEM=Linux-g++
G4WORKDIR=/home/leonid/geant4_workdir
G4LIB_USE_ZLIB=1
```

STEPS

3.2) Check if visualization is working :
> hepvis hepVisTestG4Data0.heprep



STEPS

3.3) List the folder files:

> ls -lrt

anaLhcBrich	Analysis with root of the output root file
rich1.info	Information about RICH detector
jre-6u26-linux-x64.bin	java version "1.6.0_26" – (archive)
lhcBrich-build	Directory to build the example
HepRApp.jar	File for hep rep visualisation
lhcBrich	Source code of lhcBrich detector
setup.bash	Script to define working space
TESHEP_Geant4_training_presentation.pdf	This presentation (pdf)
TESHEP_Geant4_training_presentation.odp	This presentation (odp)
jre1.6.0_26	java version "1.6.0_26"
user.properties	File produced by HepRep visualization program

STEPS

4) Enter the build directory of the lhcBrich
   > cd lhcBrich-build/

5) List the directories
   > ls

Please note : **the directory have to empty.** If not - remove everything inside (rm -rf *)

6) Setup the cmake building of the lhcBrich example:
   > cmakegeant ../lhcBrich

7) List the directories
   > ls

Please note : the directory is not empty anymore and it is ready to perform the compilation

STEPS

8) Compile the example

> make

Note you can use -j option to use more then one thread for example > make -j4 ; (where 4 is number of threads to be used).

```
Scanning dependencies of target lhcBrich
[  7%] Building CXX object CMakeFiles/lhcBrich.dir/lhcBrich.cc.o
[ 14%] Building CXX object CMakeFiles/lhcBrich.dir/src/DetectorConstruction.cc.o
[ 28%] Building CXX object CMakeFiles/lhcBrich.dir/src/HitMy.cc.o
[ 28%] Building CXX object CMakeFiles/lhcBrich.dir/src/RunAction.cc.o
[ 35%] Building CXX object CMakeFiles/lhcBrich.dir/src/SensitiveDetector.cc.o
[ 42%] Building CXX object CMakeFiles/lhcBrich.dir/src/TrackingAction.cc.o
[ 50%] Building CXX object CMakeFiles/lhcBrich.dir/src/TrackInformation.cc.o
[ 57%] Building CXX object CMakeFiles/lhcBrich.dir/src/SteppingVerbose.cc.o
[ 64%] Building CXX object CMakeFiles/lhcBrich.dir/src/PhysicsList.cc.o
[ 71%] Building CXX object CMakeFiles/lhcBrich.dir/src/StackingAction.cc.o
[ 78%] Building CXX object CMakeFiles/lhcBrich.dir/src/PrimaryGeneratorAction.cc.o
[ 85%] Building CXX object CMakeFiles/lhcBrich.dir/src/SteppingAction.cc.o
[ 92%] Building CXX object CMakeFiles/lhcBrich.dir/src/EventAction.cc.o
[100%] Linking CXX executable lhcBrich
[100%] Built target lhcBrich
```

9) Check if you you have executable

> ls → lhcBrich

STEPS

10) Run executable with no parameters

> ./lhcBrich

ERROR of the input parameters !!!

- [0] - vis.mac or run.mac or *.mac
- [1] - seed
- [2] - output root file name
- [3] - name of the particle (e+, e-, mu+, mu-, pi+, pi-, kaon+, kaon-, proton, gamma)
- [4] - particle momentum (GeV/c)
- [5] - particle theta (deg)
- [6] - particle phi (deg)

This ERROR massage is just a reminder about parameters to give to the simulation.

11) run lhcBrich-example with parameters and no visualization

> ./lhcBrich **run.mac** 123123 lhcBrich.root kaon- 20 10 90

phi angle

Run.mac or vis.mac

Random seed

Output root file

Type

Momentum

Theta angle

Output info:

```
*Baskets :       9 : Basket Size=      32000 bytes  Compression=  83.74     *
*............................................................................*
*Br   36 :trkPosZ   : trkPosZ[nPhot]/D                                       *
*Entries :     100 : Total  Size=     264644 bytes  File Size  =       3147 *
*Baskets :       9 : Basket Size=      32000 bytes  Compression=  83.90     *
*............................................................................*
*Br   37 :trkT      : trkT[nPhot]/D                                          *
*Entries :     100 : Total  Size=     264605 bytes  File Size  =       3114 *
*Baskets :       9 : Basket Size=      32000 bytes  Compression=  84.78     *
*............................................................................*
*Br   38 :trkLength : trkLength[nPhot]/D                                     *
*Entries :     100 : Total  Size=     264670 bytes  File Size  =      16623 *
*Baskets :       9 : Basket Size=      32000 bytes  Compression=  15.88     *
*............................................................................*
Time: User=0.4s Real=0.44s Sys=0.01s
```

Visualization

12) Run lhcBrich with parameters and visualization
> ./lhcBrich **vis.mac** 123123 lhcBrich_Vis.root kaon- 20 10 90

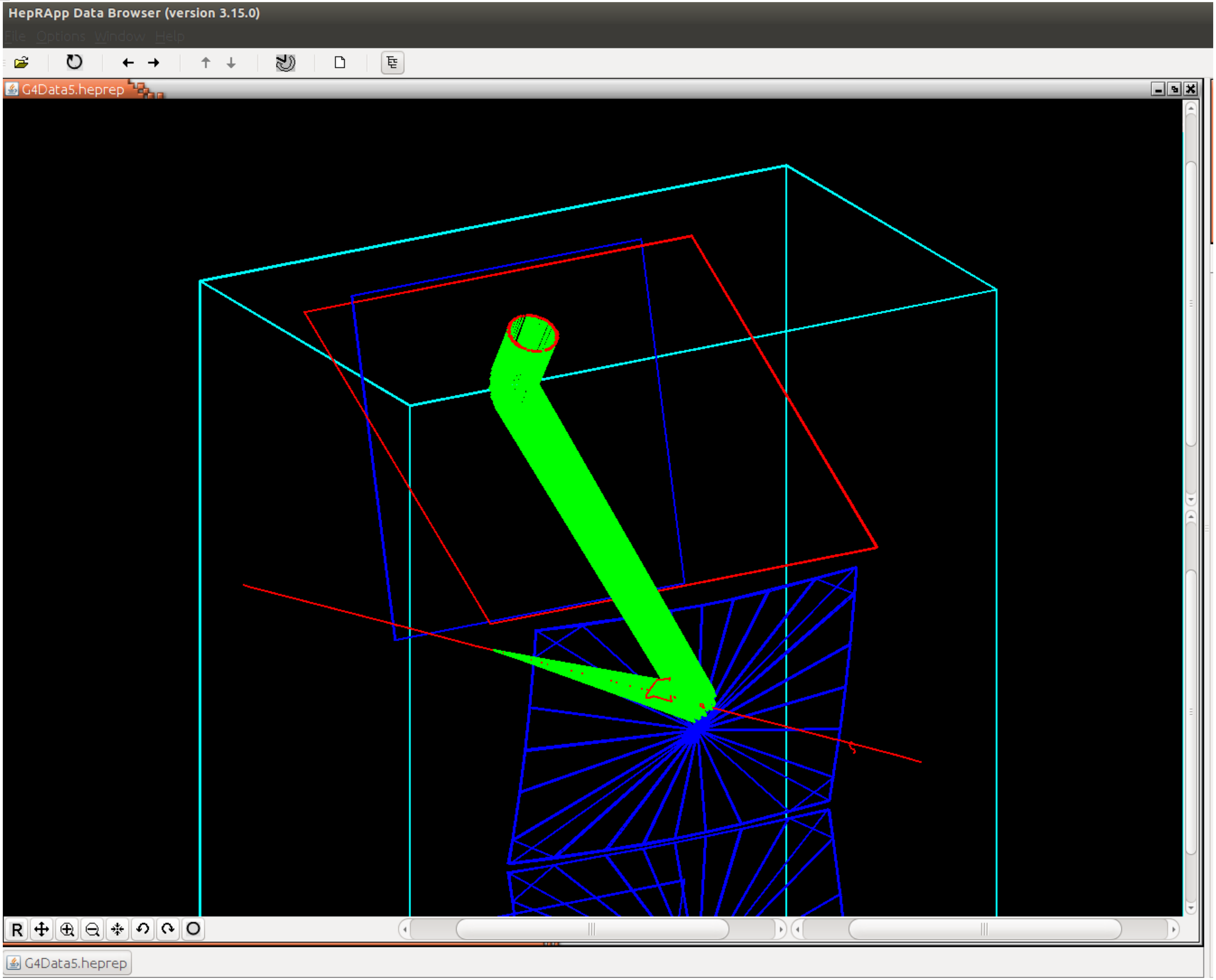
You will find:
G4Data0.heprep
G4Data1.heprep
G4Data2.heprep
G4Data3.heprep
G4Data4.heprep
G4Data5.heprep
G4Data6.heprep
G4Data7.heprep
G4Data8.heprep
G4Data9.heprep

13) visualize first files with java
> hepvis G4Data0.heprep

14) Study this geometry – make some rotations and so on....

15) visualize second files with java
> hepvis G4Data1.heprep

Visualization



Analise of output root-file

16) Compare vis.mac and run.mac

vis.mac

```
/vis/open HepRepFile
/vis/scene/create
/vis/scene/add/volume
/vis/sceneHandler/attach
/vis/viewer/flush
/vis/scene/add/trajectories smooth
/vis/scene/add/hits
/vis/viewer/set/viewpointThetaPhi 0 0 deg
/run/beamOn 10
```

run.mac

```
/run/verbose 0
/tracking/verbose 0
/event/verbose 0
/tracking/storeTrajectory 2
/run/beamOn 100
```

Number of events to simulate

17) Accumulate large enough root file with run.mac

> ./lhcBrich **run.mac** 123123 lhcBrich.root kaon- 20 10 90

Analise of output root-file

Now it is time to make analysis of the simulation with root based program

18) go to the anaLhcBrich directory
> cd ../anaLhcBrich/

19) List the folder files:
> ls

Class to Analise the root file

ana.C ana.h

Main program to setup analysis

mainAna.C

20) Run the analysis
> root -l mainAna.C

→ On plot PosX vs PosY you will see detected Cherenkov ring. (NOTE all generated events are superimposed)

→ On plot R you will see detected Cherenkov ring. Radius of this ring is proportional to Cherenkov angle.

NOTE : that position of the photon measured with PMT is ideal – the PMT position resolution does not included within Geant4 simulation. This effect can be taken into account with root analysis program.

Analise of output root-file

21) Change position resolution of the PMTs

Uncomment this line in the mainAna.C
//t->SetPMTpositionResolution(3);

Compare the RMS of the radius reconstruction with and without PMT resolution.
What is the good way to look at the resolution ?

22) What is the main contribution to the radius resolution ?

23) Generate with Gant4 Kaons and Pion with 20 GeV/c Momentum and 10 deg theta and 90 deg phi:

```
> ./lhcBrich run.mac 123123 lhcBrich_Pi_20GeV.root pi- 20 10 90
> ./lhcBrich run.mac 123123 lhcBrich_K_20GeV.root kaon- 20 10 90
```

Note : you have change the name of the output file for two particles.

In analysis program (mainAna.C) you can change the name of input root file for analysis. Comment uncomment the lines.

```
//ana *t = new ana("../lhcBrich/lhcBrich_K_20GeV.root");
//ana *t = new ana("../lhcBrich/lhcBrich_Pi_20GeV.root");
```

24) With ana program find **compare** and remember radius and RMS for two particles types.

STEPS

25) Which particle have bigger radius of the Cherenkov ring ? Why ? Is it consistent with Cherenkov formula ?

$$\cos\theta_c = \frac{1}{n\beta}$$

26) We can define separation power between Kaon (K) and Pion (pi) in such way:

$$\text{Separation Power} = \frac{\text{Radius}_K - \text{Radius}_{pi}}{(\text{RMS}_K + \text{RMS}_{pi})/2}$$

27) Find separation power for Kaons and Pion with 20 GeV/c.

28) Generate with Gant4 Kaons and Pion with 50 GeV/c Momentum and 10 deg theta and 90 deg phi:

> ./lhcBrich run.mac 123123 **lhcBrich_Pi_50GeV.root** pi- **50** 10 90
> ./lhcBrich run.mac 123123 **lhcBrich_K_50GeV.root** kaon- **50** 10 90

STEPS

Geant4 first steps (practical work)

29) Find separation power for Kaons and Pion with 50 GeV/c. Compare this results with 20 GeV/c particles.

30) Generate with Gant4 Kaons and Pion with 100 GeV/c Momentum and 10 deg theta and 90 deg phi:

> ./lhcBrich run.mac 123123 **lhcBrich_Pi_100GeV.root** pi- **100** 10 90

> ./lhcBrich run.mac 123123 **lhcBrich_K_100GeV.root** kaon- **100** 10 90

31) Find separation power for Kaons and Pion with 100 GeV/c. Compare this results with 100 GeV/c particles. Can this detector distinguish between 100 GeV/c Kaon and 100 GeV/c pion ? Why ?

STEPS
Back to Geant

32) Add a volume of aerogel into your simulation (detector construction class). To do it just uncomment this piece of code:

Please note that the code is in lhcBrich/src directory not in your build directory.

```
G4VPhysicalVolume *aerogel_body_physical
      = new G4PVPlacement(Tr, //Transformation
                          aerogel_body_logical, //its logical volume
                         "aerogel_body", //its name
                         c4f10_body_logical, //its mother volume
                         false, //no boolean operation
                         0); //copy number
aerogel_body_physical->GetName();
```

After the file have been changed one need to recompile the code. For this go to your build directory (lhcBrich-build).

Recompile the code :
```
> make
```

STEPS

33) Check with visualization new geometry
> ./lhcBrich **vis.mac** 123123 lhcBrich_Vis.root kaon- 20 5 90

34) Generate 100 kaons- with 20 GeV/c momentum Theta = 10 deg and phi = 90 deg.
> ./lhcBrich run.mac 123123 **lhcBrich_K_5GeV_aerogel.root** kaon- **20** 5 90

35) Check with analysis program how does picture of ring change.

36) Simulate distortion of the phi and theta angles in the primary generation action class.

Uncomment these lines here:
```
//_ThetaAngle = _ThetaAngle + (-1 + 2*G4UniformRand())*2*TMath::Pi()/360;//mearing of one degree
//_PhiAngle = _PhiAngle + (-1 + 2*G4UniformRand())*2*TMath::Pi()/360;//mearing of one degree
```

Conclusions. Useful links.

- Homepage:
  http://geant4.cern.ch/

- Main publication:
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
  Volume 506, Issue 3, 1 July 2003, Pages 250–303
  Geant4—a simulation toolkit

- Lund Universit, Sweden 7-11 April 2014:
  http://indico.hep.lu.se/conferenceDisplay.py?confId=1378

- LAL-Orsay, France 19-23 May 2014:
  http://groups.lal.in2p3.fr/ED-geant4/2014-19-23-may/program/

- List of Geant4 – related tutorials
  http://geant4.in2p3.fr/spip.php?rubrique6

Backup

Outline

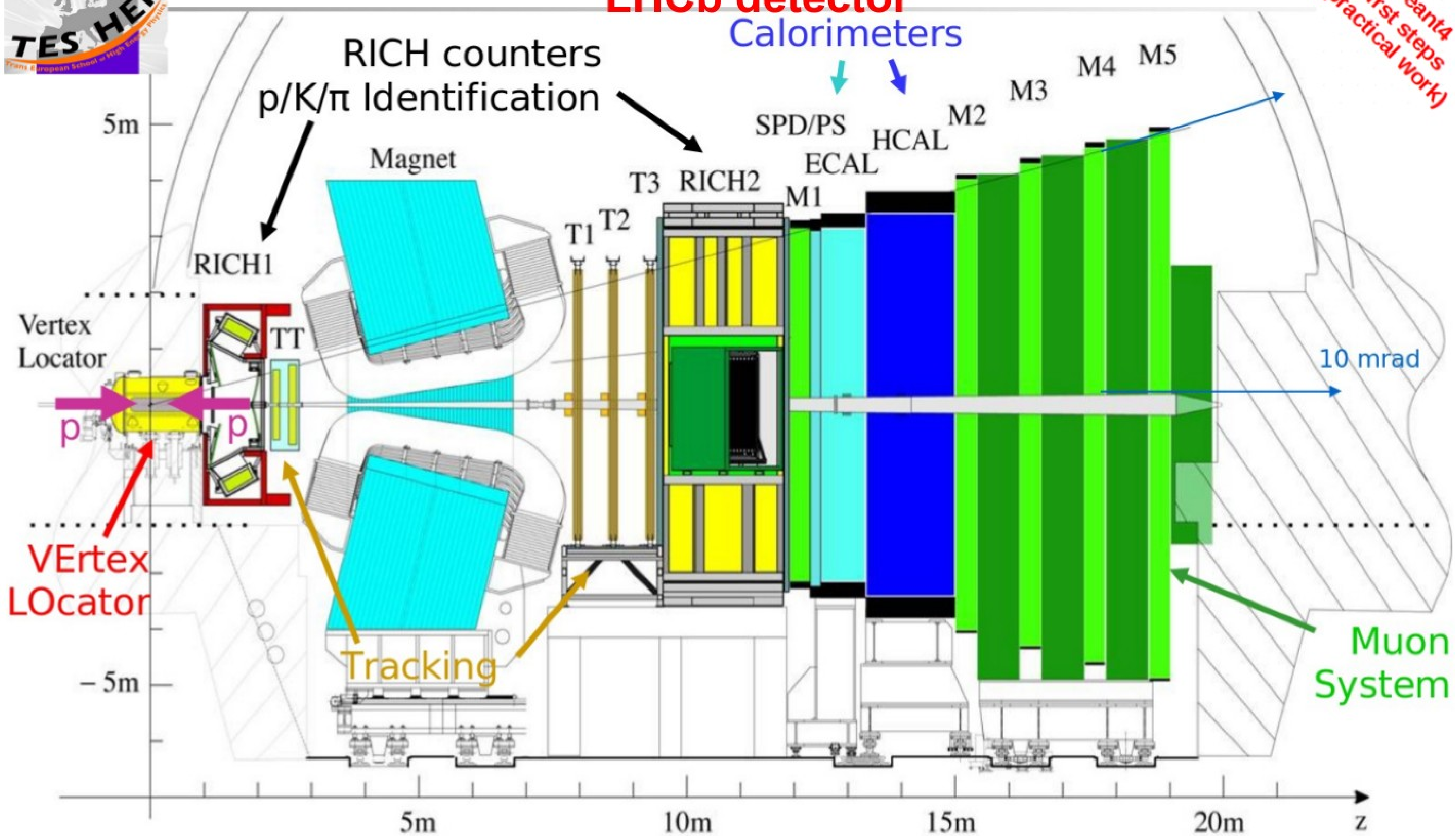
1. Introduction

2. Example: LHCb-RICH1

- → Physics
- → Simulation with Geant4
- → Analysis with root

3. Step by step exercise

LHCb detector



Vertex reconstruction:
VELO

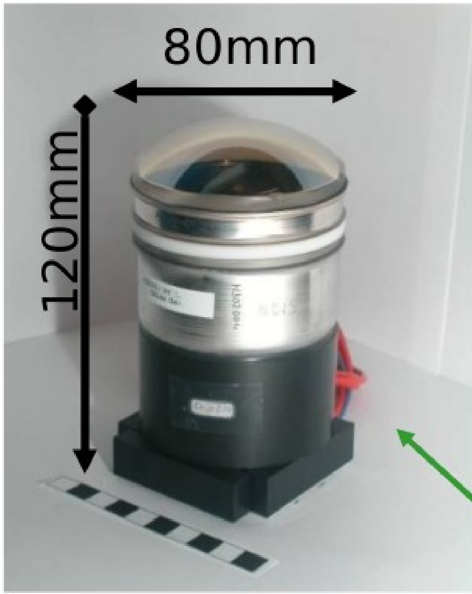
Kinematics:
Magnet
Tracker
Calorimeters

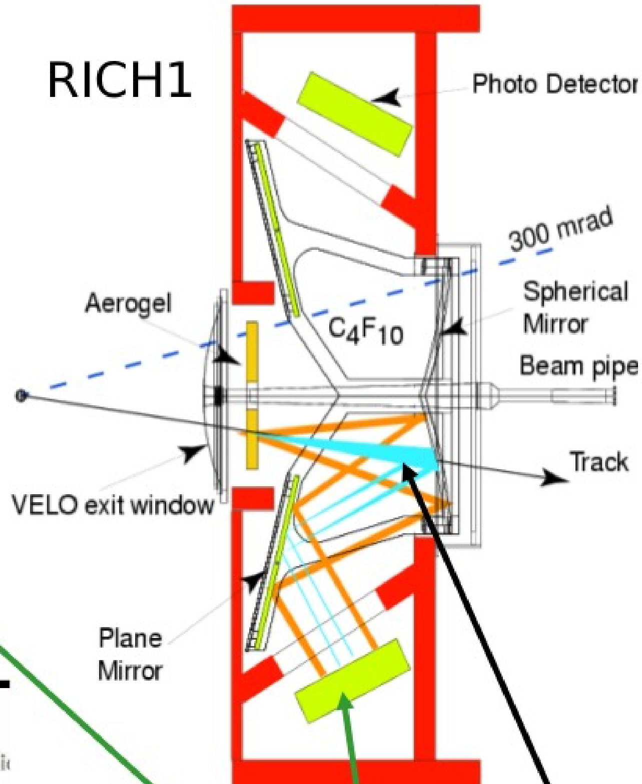
PID:
RICHs
Calorimeters
Muon Chambers

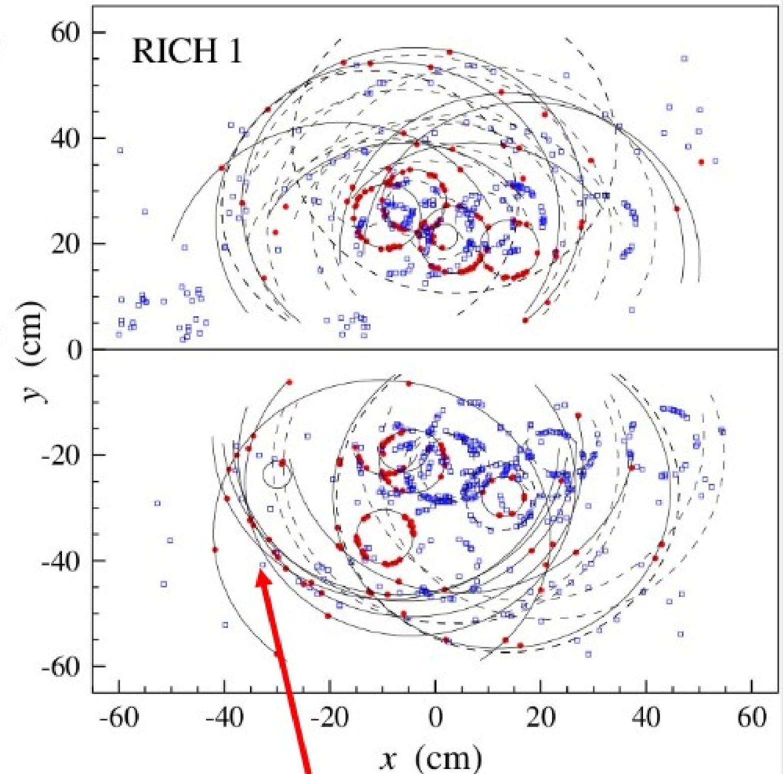
Trigger:
Muon Chambers
Calorimeters
Tracker

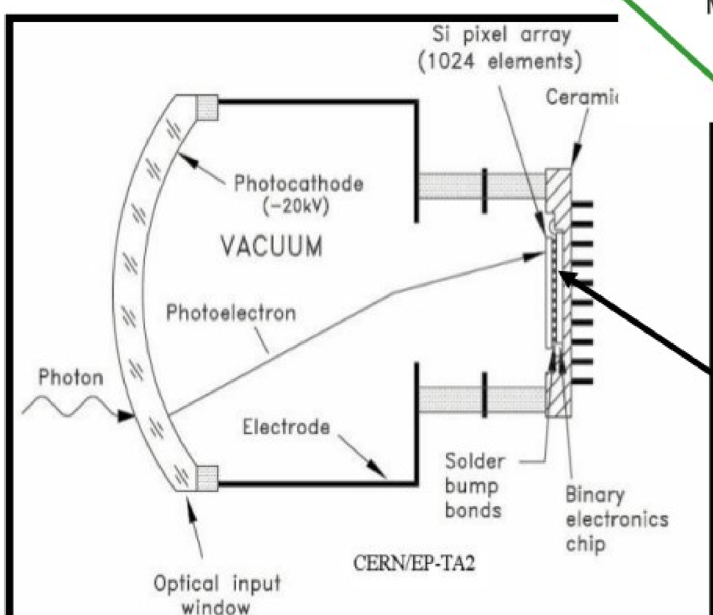
Photo detector plane

Geant4
first steps
(practical work)









Photons from Cerenkov cone focused onto rings recorded by **Hybrid Photo Diodes arrays**, out of acceptance. Each containing a 1024 Si pixel array.

Why do we use gas as Cherenkov radiator

$$\beta = \frac{1}{n\cos(\theta)} \rightarrow \frac{\sigma_\beta}{\beta} = \sigma_\theta \tan(\theta) \rightarrow \frac{\sigma_\beta}{\beta} \to 0 \quad \theta \to 0 \quad \boxed{n \to 1}$$

Separation power $N\sigma$ for materials with $n \to 1$ can be computed:

$$N_\sigma = \frac{\theta_1 - \theta_2}{\sigma_\theta} \sim \frac{|m_1^2 - m_2^2|}{2p^2\sigma_\theta\sqrt{n^2-1}}$$

For solid bodies and liquids minimum refractive index (n) is around 1.28

$n \to 1$

Gas

$n = 1 + k\,p \rightarrow$ Pressure

Aerogel

$n^2 = 1 + 0.438\,\mathrm{cm}^3/\mathrm{g}\ \rho \rightarrow$ Density

$$N_{Cherenkov\ \ light} \sim \left(1 - \frac{1}{n^2\beta^2}\right) L \rightarrow \boxed{\text{Big size of radiator}}$$

Simulation sequence