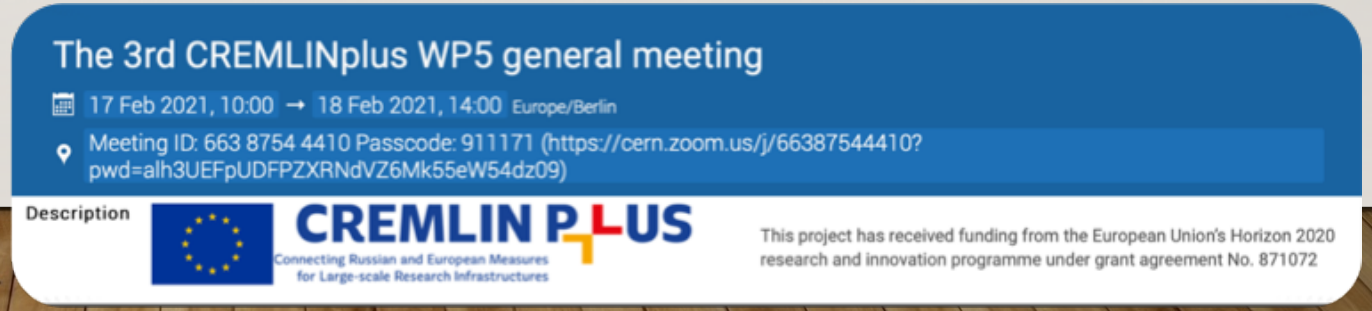
TASK4: C+RWELL SIMULATION

E. DE LUCIA, R. FARINELLI, M.GIOVANNETTI, L. LAVEZZI, G. MORELLO

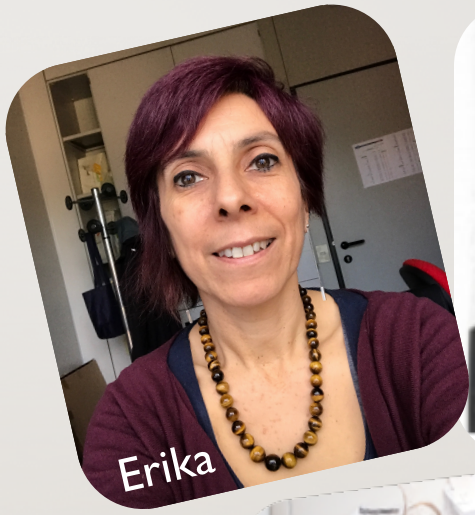
ON BEHALF OF THE C+RWELL GROUP



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

CONCLUSIONS @CREMLINPLUS WP5 GM 28-29 SEP 2020

Newly established working group exploiting KLOE-2 and BESIII expertise and skills



CONCLUSIONS @CREMLINPLUS WP5 GM 28-29 SEP 2020

1) DD4HEP framework for SCTF detector simulation

Hands-on started on proxima server @ BINP & First tutorial with Build and Run primary generators done

To do:

- Insert updated detector configuration as from mechanical group studies
- Perform soft pion studies
- Vertex reconstruction efficiency and resolution

2) Detector Response Parametrisation for fast simulation

Preliminary distributions for Cluster Size & Charge *without resistive stage simulation* shown

To do:

- Simulate resistive configuration
- Parameters tuning @ $\theta = 0^{\circ}$ and 0.5 kV/cm drift field with μRWELL reference data: threshold, noise, space and time resolutions
- Validation with drift fields > 0.5 kV/cm and track incident angle scan
- Insert DRP in DD4HEP framework

DD4HEP FRAMEWORK FOR SCTF DETECTOR SIMULATION (I)

- Started playing with the C+RWELL template in aurora/DetectorDescription/VertexTracker/CmuRWELLGeo and following the *How to implement sub-detector mode*l instructions on the wiki:

  https://ctd.inp.nsk.su/wiki/index.php/How-to:_implement_subdetector_model#Set_up_the_AURORA_work_area

- Several useful tools to test sub-detectors geometry (*testLoadGeometry.py* and *testOverlap.py*)

```
[edelucia@proxima aurora]$ testLoadGeometry.py -s CmuRWELL
using subsystems aliases :
        CmuRWELL
detector_geo_input:
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_de
tector_geoinitialize.xml
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/CmuRWELLGeo/CmuR
WELLGeom_def.xml
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_de
tector_geofinalize.xml
GeometryTools    INFO  Start test xml load
Info in <TGeoManager::TGeoManager>: Geometry default, Detector Geometry created
Info in <TGeoManager::SetTopVolume>: Top volume is world_volume. Master volume is world_volume
Info in <TGeoNavigator::BuildCache>: --- Maximum geometry depth set to 100
CmuRWELLConstru...   INFO create_CmuRWELL() is started
CmuRWELLConstru...   INFO  - det_name: CmuRWELL
CmuRWELLConstru...   INFO create_CmuRWELL() is finished
Info in <TGeoManager::CheckGeometry>: Fixing runtime shapes...
Info in <TGeoManager::CheckGeometry>: ...Nothing to fix
Info in <TGeoManager::CloseGeometry>: Counting nodes...
Info in <TGeoManager::Voxelize>: Voxelizing...
Info in <TGeoManager::CloseGeometry>: Building cache...
Info in <TGeoManager::CountLevels>: max level = 1, max placements = 5
Info in <TGeoManager::CloseGeometry>: 6 nodes/ 4 volume UID's in Detector Geometry
Info in <TGeoManager::CloseGeometry>: ----------------modeler ready----------------
GeometryTools    INFO  End test xml load
```

```
[edelucia@proxima aurora]$ testOverlap.py -s CmuRWELL
using subsystems aliases :
        CmuRWELL
detector_geo_input:
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_de
tector_geoinitialize.xml
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/CmuRWELLGeo/CmuR
WELLGeom_def.xml
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_de
tector_geofinalize.xml
GeometryTools    INFO  Start test overlap
Info in <TGeoNodeMatrix::CheckOverlaps>: Checking overlaps for world_volume and daughters within 0.01
Check overlaps:      [==========]    6 [100.00 %]          00:00
Info in <TGeoNodeMatrix::CheckOverlaps>: Number of illegal overlaps/extrusions : 0

GeometryTools    INFO  End test overlap
```

DD4HEP FRAMEWORK FOR SCTF DETECTOR SIMULATION (II)

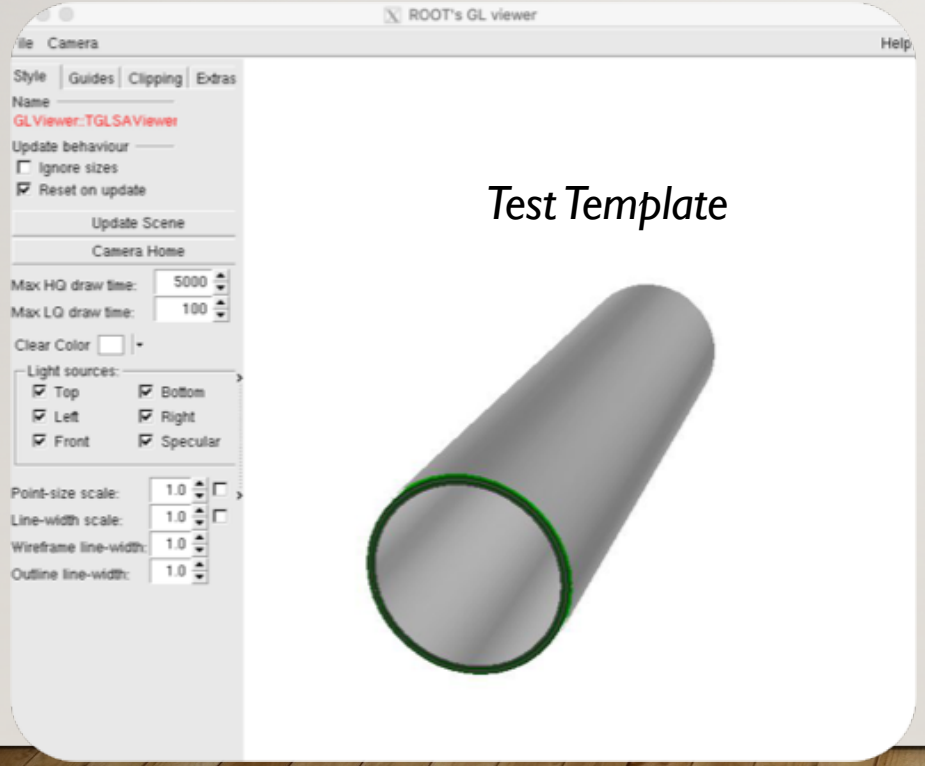
- Also listing of sub-detectors materials *(MaterialScan.py)*
- Present materials are listed in DetectorDescription/DetBase/xml/Materials/material_mixture.xml.
  To be updated to add C+RWELL materials

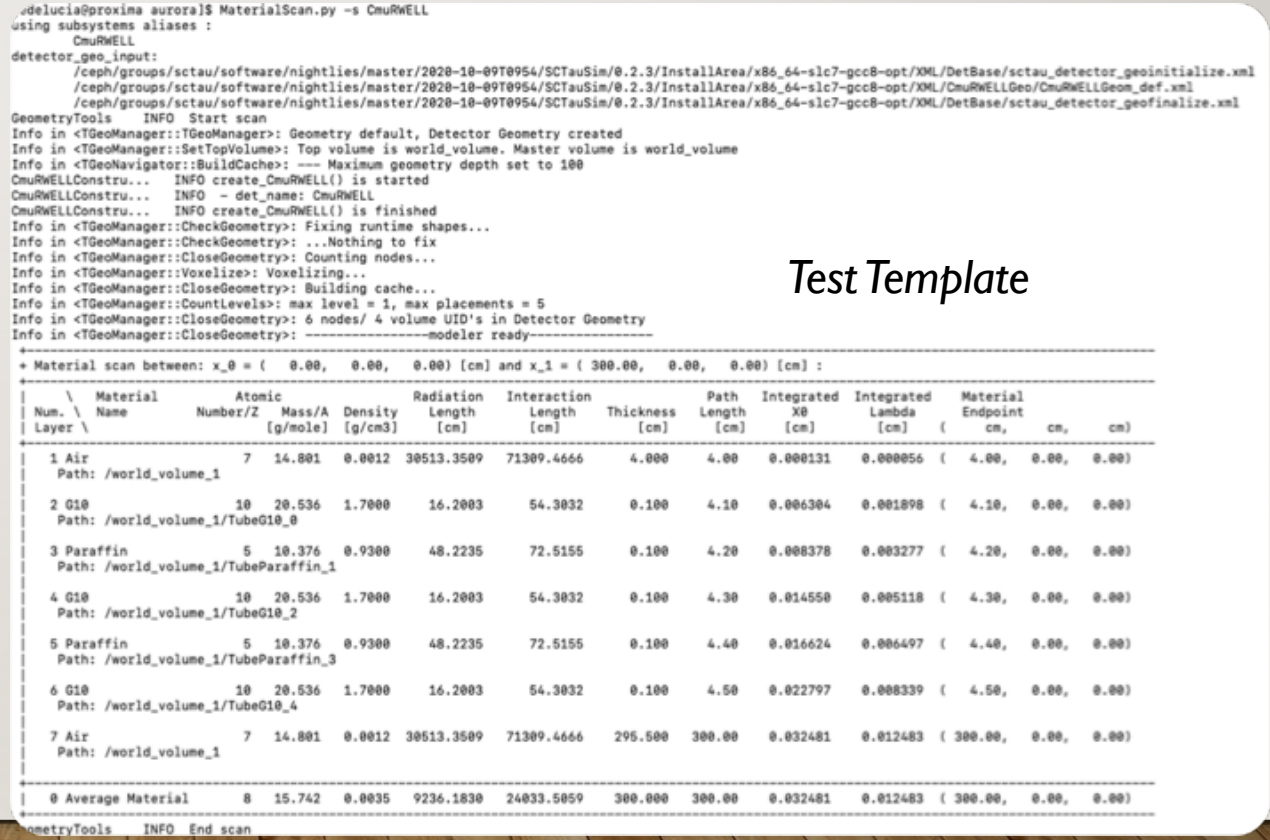
```
[edelucia@proxima aurora]$ MaterialScan.py -s CmuRWELL
using subsystems aliases :
        CmuRWELL
detector_geo_input:
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_detector_geoinitialize.xml
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/CmuRWELLGeo/CmuRWELLGeom_def.xml
        /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_detector_geofinalize.xml
GeometryTools    INFO  Start scan
Info in <TGeoManager::TGeoManager>: Geometry default, Detector Geometry created
Info in <TGeoManager::SetTopVolume>: Top volume is world_volume. Master volume is world_volume
Info in <TGeoNavigator::BuildCache>: --- Maximum geometry depth set to 100
CmuRWELLConstru...   INFO create_CmuRWELL() is started
CmuRWELLConstru...   INFO  - det_name: CmuRWELL
CmuRWELLConstru...   INFO create_CmuRWELL() is finished
Info in <TGeoManager::CheckGeometry>: Fixing runtime shapes...
Info in <TGeoManager::CheckGeometry>: ...Nothing to fix
Info in <TGeoManager::CloseGeometry>: Counting nodes...
Info in <TGeoManager::Voxelize>: Voxelizing...
Info in <TGeoManager::CloseGeometry>: Building cache...
Info in <TGeoManager::CountLevels>: max level = 1, max placements = 5
Info in <TGeoManager::CloseGeometry>: 6 nodes/ 4 volume UID's in Detector Geometry
Info in <TGeoManager::CloseGeometry>: ----------------modeler ready----------------
 +------------------------------------------------------------------------------------------------------------------------------------------------------
 + Material scan between: x_0 = (    0.00,    0.00,    0.00) [cm] and x_1 = ( 300.00,    0.00,    0.00) [cm] :
 +------------------------------------------------------------------------------------------------------------------------------------------------------
 |      \   Material            Atomic                 Radiation   Interaction              Path   Integrated  Integrated    Material
 | Num. \   Name            Number/Z   Mass/A  Density    Length        Length   Thickness   Length       X0       Lambda      Endpoint
 | Layer \                            [g/mole] [g/cm3]     [cm]          [cm]        [cm]     [cm]      [cm]        [cm]    (     cm,      cm,      cm)
 +------------------------------------------------------------------------------------------------------------------------------------------------------
 |   1 Air                    7   14.801   0.0012  30513.3509   71309.4666      4.000     4.00   0.000131    0.000056  (   4.00,    0.00,    0.00)
 |    Path: /world_volume_1
 |
 |   2 G10                   10   20.536   1.7000     16.2003      54.3032      0.100     4.10   0.006304    0.001898  (   4.10,    0.00,    0.00)
 |    Path: /world_volume_1/TubeG10_0
 |
 |   3 Paraffin               5   10.376   0.9300     48.2235      72.5155      0.100     4.20   0.008378    0.003277  (   4.20,    0.00,    0.00)
 |    Path: /world_volume_1/TubeParaffin_1
 |
 |   4 G10                   10   20.536   1.7000     16.2003      54.3032      0.100     4.30   0.014550    0.005118  (   4.30,    0.00,    0.00)
 |    Path: /world_volume_1/TubeG10_2
 |
 |   5 Paraffin               5   10.376   0.9300     48.2235      72.5155      0.100     4.40   0.016624    0.006497  (   4.40,    0.00,    0.00)
 |    Path: /world_volume_1/TubeParaffin_3
 |
 |   6 G10                   10   20.536   1.7000     16.2003      54.3032      0.100     4.50   0.022797    0.008339  (   4.50,    0.00,    0.00)
 |    Path: /world_volume_1/TubeG10_4
 |
 |   7 Air                    7   14.801   0.0012  30513.3509   71309.4666    295.500   300.00   0.032481    0.012483  ( 300.00,    0.00,    0.00)
 |    Path: /world_volume_1
 |
 +------------------------------------------------------------------------------------------------------------------------------------------------------
 |   0 Average Material       8   15.742   0.0035   9236.1830   24033.5059    300.000   300.00   0.032481    0.012483  ( 300.00,    0.00,    0.00)
 +------------------------------------------------------------------------------------------------------------------------------------------------------
GeometryTools    INFO  End scan
```

Test Template

DD4HEP FRAMEWORK FOR SCTF DETECTOR SIMULATION (II)

- Also listing of sub-detectors materials *(MaterialScan.py)*
- Present materials are listed in DetectorDescription/DetBase/xml/Materials/material_mixture.xml.
  To be updated to add C+RWELL materials
- Geometry display *(GeoDisplay.py)*





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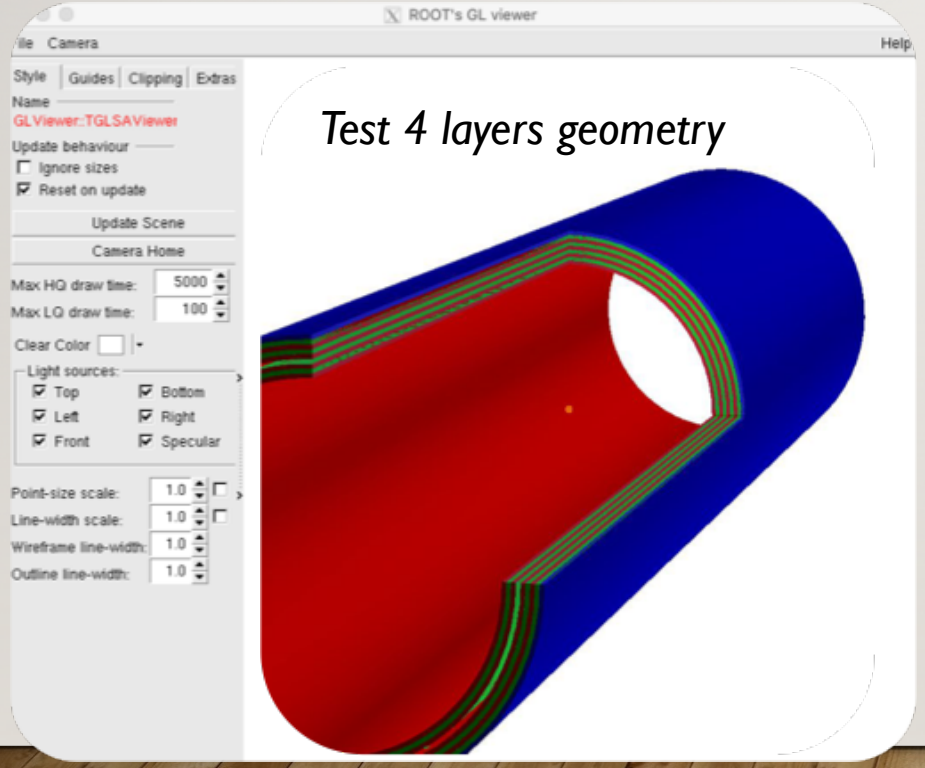


```
delucia@proxima aurora]$ MaterialScan.py -s CmuRWELL
using subsystems aliases :
       CmuRWELL
detector_geo_input:
       /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_detector_geoinitialize.xml
       /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/CmuRWELLGeo/CmuRWELLGeom_def.xml
       /ceph/groups/sctau/software/nightlies/master/2020-10-09T0954/SCTauSim/0.2.3/InstallArea/x86_64-slc7-gcc8-opt/XML/DetBase/sctau_detector_geofinalize.xml
GeometryTools    INFO  Start scan
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Info in <TGeoManager::SetTopVolume>: Top volume is world_volume. Master volume is world_volume
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Info in <TGeoManager::CloseGeometry>: ----------------modeler ready----------------
```

Test Template

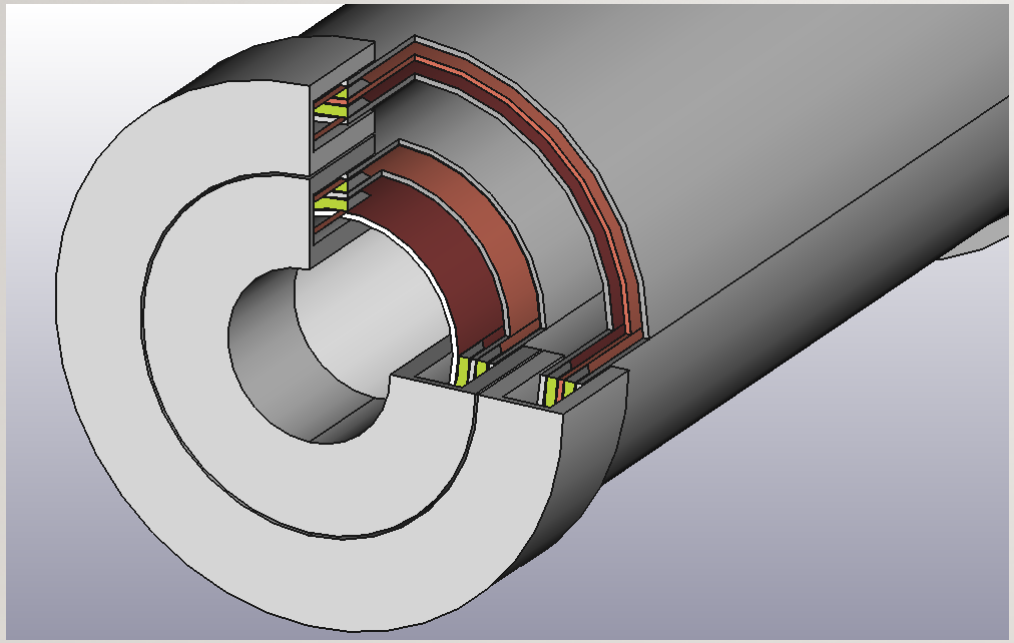
+ Material scan between: x_0 = (0.00, 0.00, 0.00) [cm] and x_1 = (300.00, 0.00, 0.00) [cm] :

Num. \ Layer	Material \ Name	Atomic Number/Z	Mass/A [g/mole]	Density [g/cm3]	Radiation Length [cm]	Interaction Length [cm]	Thickness [cm]	Path Length [cm]	Integrated X0 [cm]	Integrated Lambda [cm]	Material Endpoint (cm, cm, cm)
1	Air	7	14.801	0.0012	30513.3509	71309.4666	4.000	4.00	0.000131	0.000056	(4.00, 0.00, 0.00)
	Path: /world_volume_1										
2	G10	10	20.536	1.7000	16.2003	54.3032	0.100	4.10	0.006304	0.001898	(4.10, 0.00, 0.00)
	Path: /world_volume_1/TubeG10_0										
3	Paraffin	5	10.376	0.9300	48.2235	72.5155	0.100	4.20	0.008378	0.003277	(4.20, 0.00, 0.00)
	Path: /world_volume_1/TubeParaffin_1										
4	G10	10	20.536	1.7000	16.2003	54.3032	0.100	4.30	0.014550	0.005118	(4.30, 0.00, 0.00)
	Path: /world_volume_1/TubeG10_2										
5	Paraffin	5	10.376	0.9300	48.2235	72.5155	0.100	4.40	0.016624	0.006497	(4.40, 0.00, 0.00)
	Path: /world_volume_1/TubeParaffin_3										
6	G10	10	20.536	1.7000	16.2003	54.3032	0.100	4.50	0.022797	0.008339	(4.50, 0.00, 0.00)
	Path: /world_volume_1/TubeG10_4										
7	Air	7	14.801	0.0012	30513.3509	71309.4666	295.500	300.00	0.032481	0.012483	(300.00, 0.00, 0.00)
	Path: /world_volume_1										
0	Average Material	8	15.742	0.0035	9236.1830	24033.5059	300.000	300.00	0.032481	0.012483	(300.00, 0.00, 0.00)

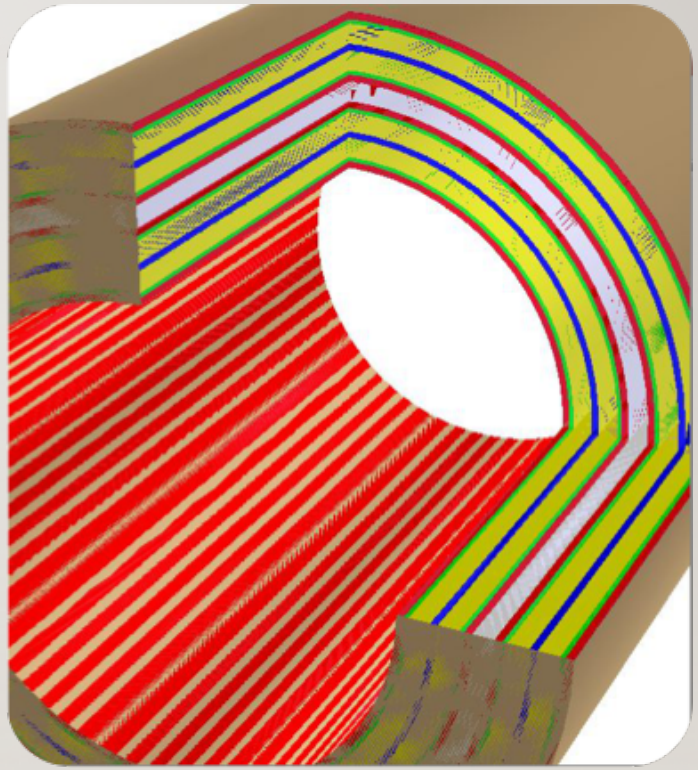
```
GeometryTools    INFO  End scan
```

READY TO INSERT OUR FIRST C+RWELL GEOMETRY

In *CmuRWELLGeom_geo.xml* the N. 2 small gap B2B C+layers geometry has been implemented



- 2 x 1 cm gas gap/B2B device
- 4 cm global sampling gas, readout in micro-TPC mode
- 1.72÷1.92% X0 depending on material choices for mechanics, cathode and faraday cage
- Cross-checking the composition of materials in official libraries.
  To be inserted:
  DLC, Prepreg & MILLIFOAM



Screenshot from GeoDisplay.py CmuRWELL

PRODUCE & SAVE GEANT4 HITS (I)

- Define the detector *sensitive layer/material* in the C+RWELL geometry xml files with the attributes sensitive="yes" type="SimpleTrackerSD"
- *DetectorDescription/DetSensitive/* contains all new definitions of sensitive readouts, the dedicated readout type for sensitive detector C+RWELL to be inserted here when ready
- *Full simulation* using */home/edelucia/workarea/aurora/Simulation/G4Sim/G4SimExamples/share/fullsim_example.py*

Generate 100 MeV pions from ParticleGun and *Save* Geant4 hits

```
# DD4hep geometry service
# Parses the given xml file
from Configurables import GeoSvc

from DetBase.DetConfigurator import DetConfigurator
detector_conf = DetConfigurator()
print 'detector_conf = ', detector_conf
detector_conf.activateSubsystems( [ 'CmuRWELL'] )
#detector_conf.activateSubsystems( [ 'ALLWELL' ] )
#detector_conf.activateSubsystems( [ 'ALL' ] )
#detector_conf.activateSubsystems( [ 'Trackers' ] )
print 'activate subsystem detector_conf = ', detector_conf

detector_geo_input = detector_conf.getGeoConfiguration()

print 'detector_geo_input =',detector_geo_input

geoservice = GeoSvc("GeoSvc", detectors=detector_geo_input, OutputLevel=INFO)

# Geant4 service
# Configures the Geant simulation: geometry, physics list and user actions
from Configurables import SimG4Svc
# giving the names of tools will initialize the tools of that type
from Configurables import SimG4FullSimActions

simAct = SimG4FullSimActions("simActions")
simAct.enableHistory = True
simAct.energyCut = 0.1*units.GeV
```

```
# first, create a tool that saves the tracker hits
# Name of that tool in GAUDI is "XX/YY" where XX is the tool class name ("SimG4SaveTrackerHits")
# and YY is the given name ("saveTrackerHits")

saveCmuRWELLtool = SimG4SaveTrackerHits("saveCmuRWELLHits", readoutNames = ["CmuRWELL_Readout"])
saveCmuRWELLtool.positionedTrackHits.Path = "positionedCmuRWELLHits"
saveCmuRWELLtool.trackHits.Path = "CmuRWELLHits"
saveCmuRWELLtool.digiTrackHits.Path = "digiCmuRWELLHits"

#saveDCtool = SimG4SaveTrackerHits("saveDCHits", readoutNames = ["MainTracker_Readout"])
#saveDCtool.positionedTrackHits.Path = "positionedDCHits"
#saveDCtool.trackHits.Path = "dcHits"
#saveDCtool.digiTrackHits.Path = "digiDCHits"

#saveFARICHtool = SimG4SaveTrackerHits("saveFarichHits", readoutNames = ["FarichBarrelReadout"])
#saveFARICHtool.positionedTrackHits.Path = "positionedFarichHits"
#saveFARICHtool.trackHits.Path = "farichHits"
#saveFARICHtool.digiTrackHits.Path = "digiFarichHits"

saveParticleHistorytool = SimG4SaveParticleHistory("saveParticleHistory")
saveParticleHistorytool.mcParticles = "secondaryParticles"
saveParticleHistorytool.genVertices = "secondaryVertices"

# next, create the G4 algorithm, giving the list of names of tools ("XX/YY")
particle_converter = SimG4PrimariesFromEdmTool("EdmConverter")
particle_converter.genParticles.Path = "allGenParticles"
geantsim = SimG4Alg(
    "SimG4Alg",
    outputs = [
        saveCmuRWELLtool.getFullName(),
        saveParticleHistorytool.getFullName()
    ],
    eventProvider=particle_converter
)
```

PRODUCE & SAVE GEANT4 HITS (I)

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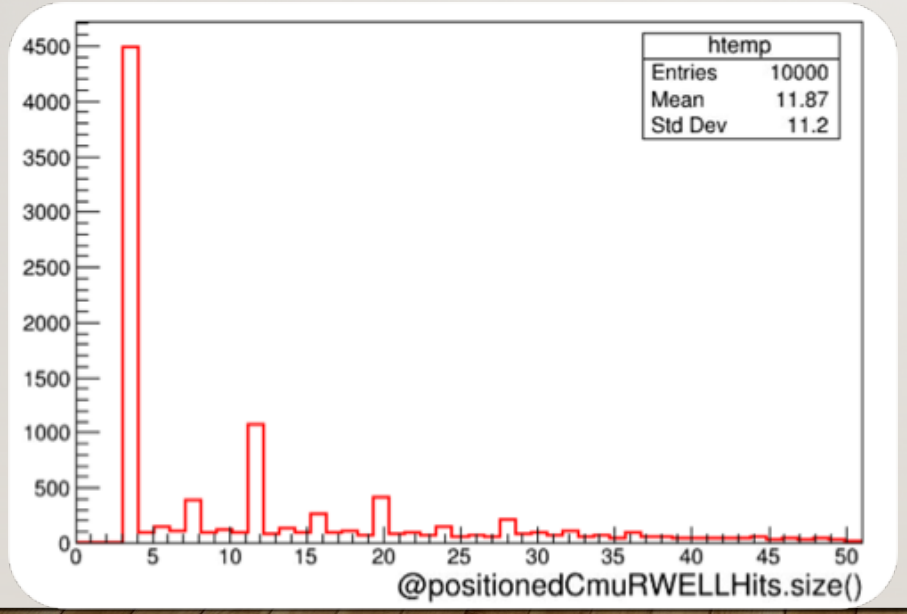
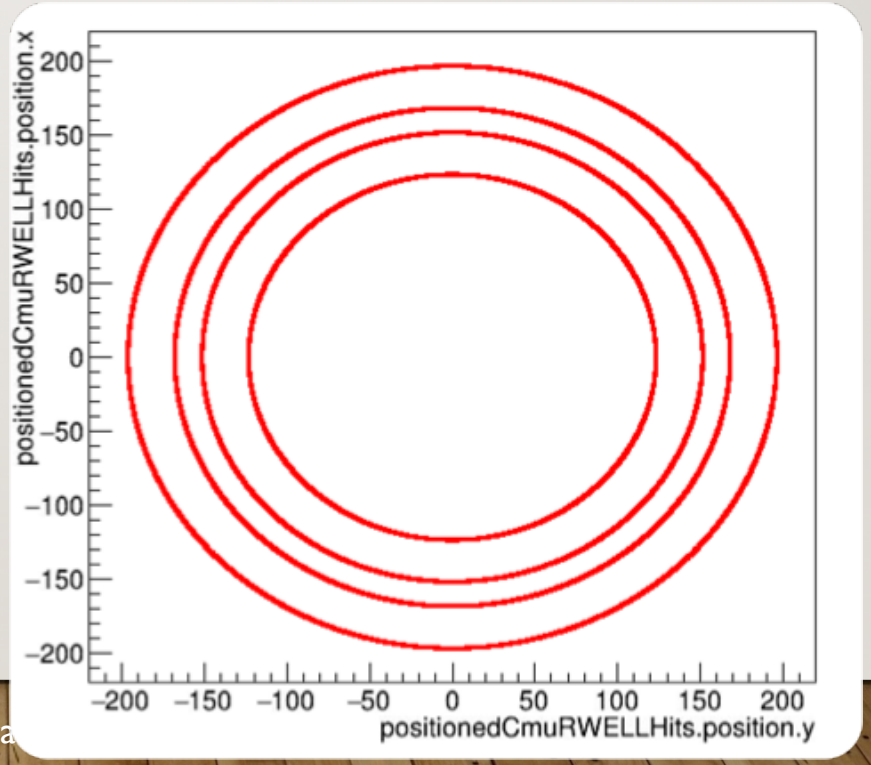
- *DetectorDescription/DetSensitive/* contains all new definitions of sensitive readouts, dedicated readout type for sensitive detector C+RWELL to be inserted here when ready
- *Full simulation* using */home/edelucia/workarea/aurora/Simulation/G4Sim/G4SimExamples/share/fullsim_example.py*

Generate 100 MeV pions from ParticleGun and *Save* Geant4 hits

$75° < \theta < 105°$
$0° < \phi < 360°$





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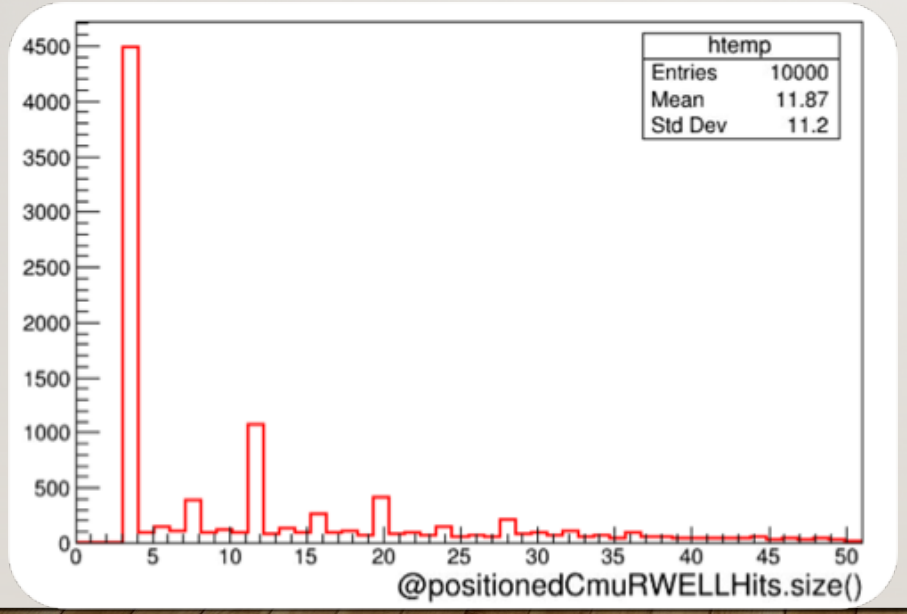
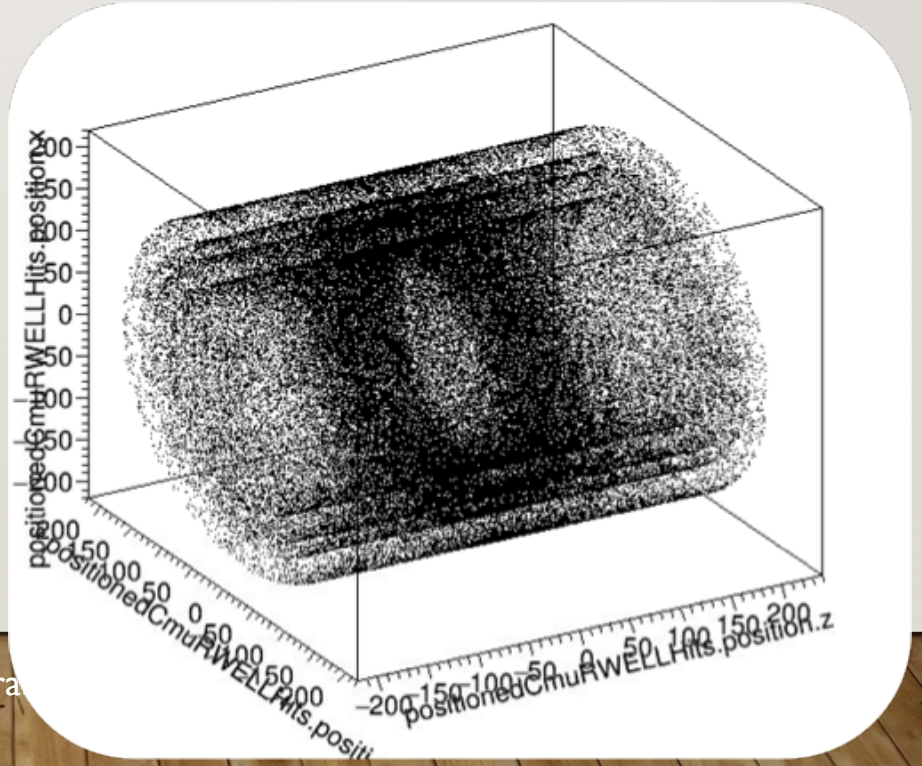
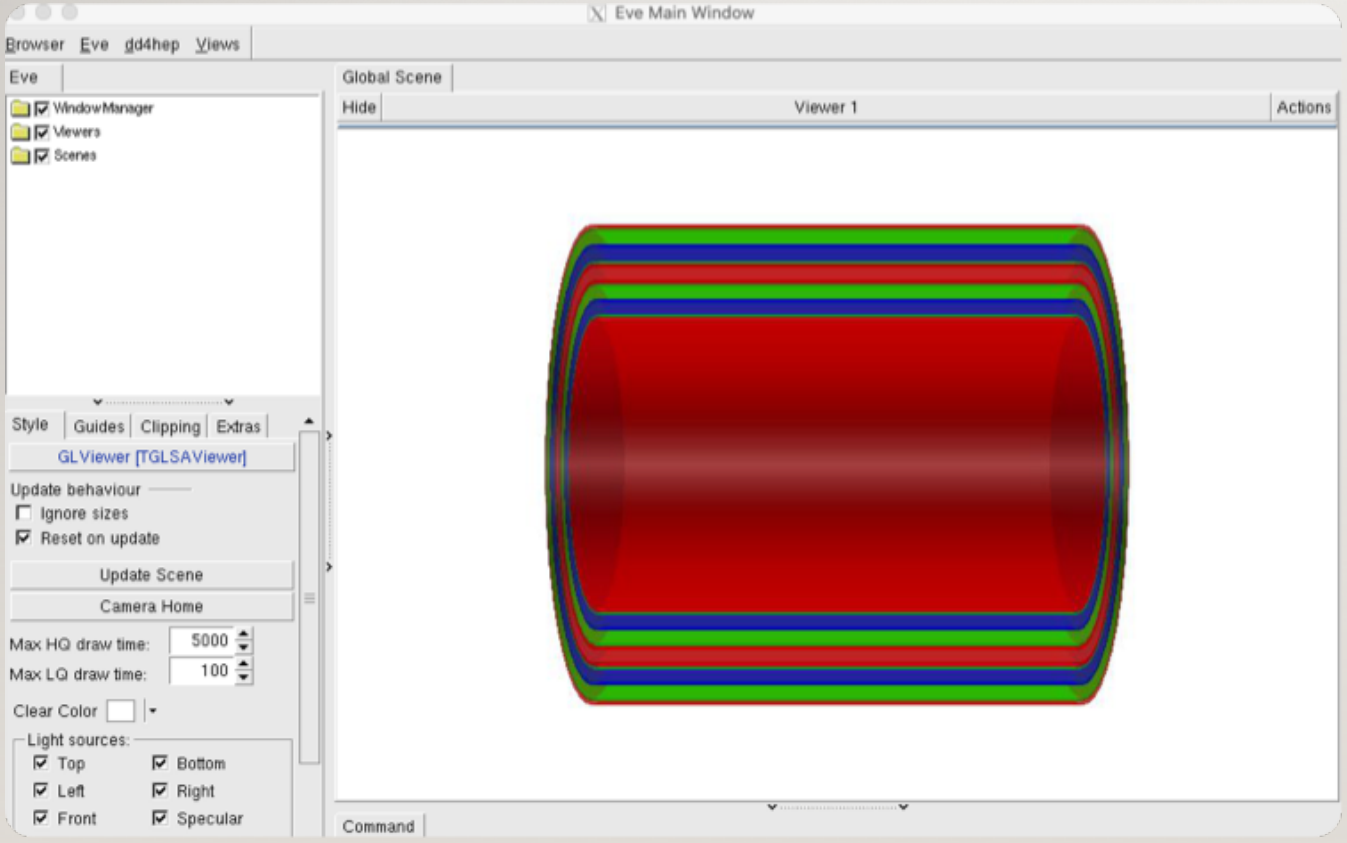
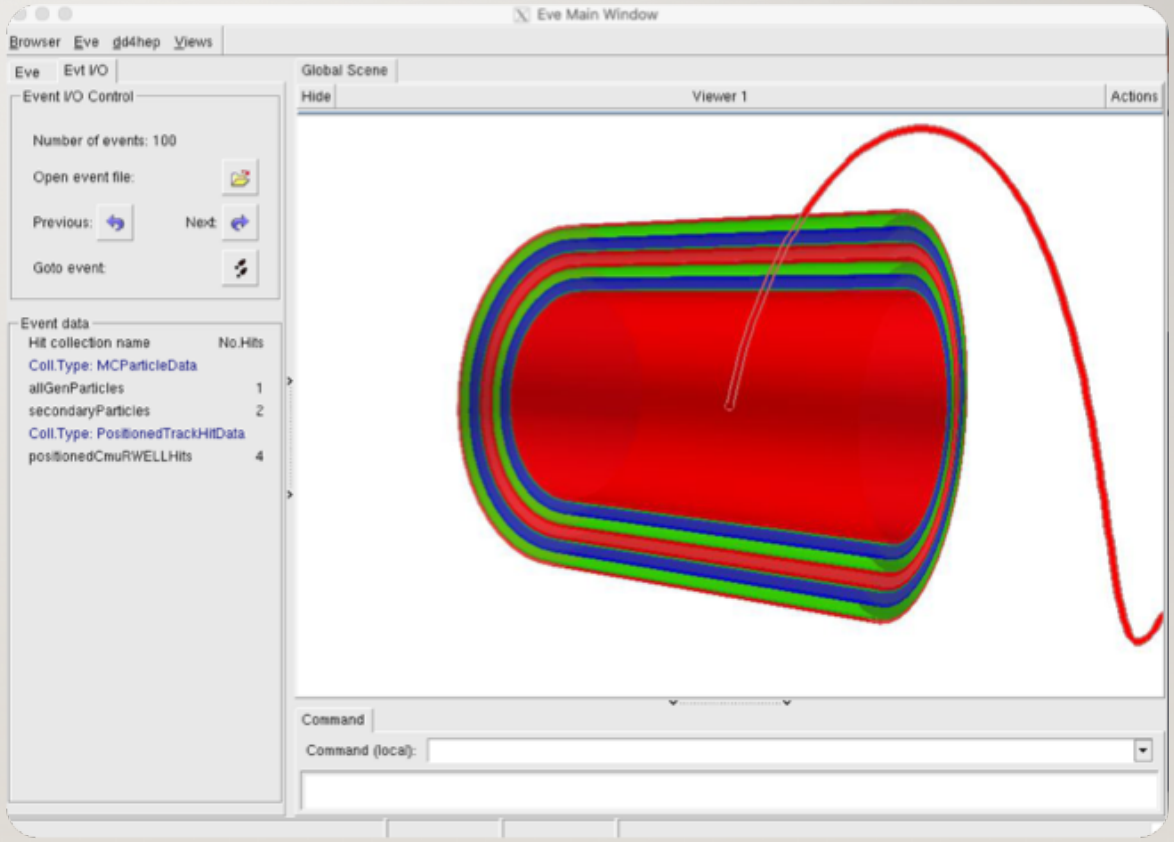




EVENT DISPLAY

- EventDisplay.py --subsystems CmuRWELL gun_pi_g4sim_100MeV.root





DETECTOR RESPONSE PARAMETRISATION

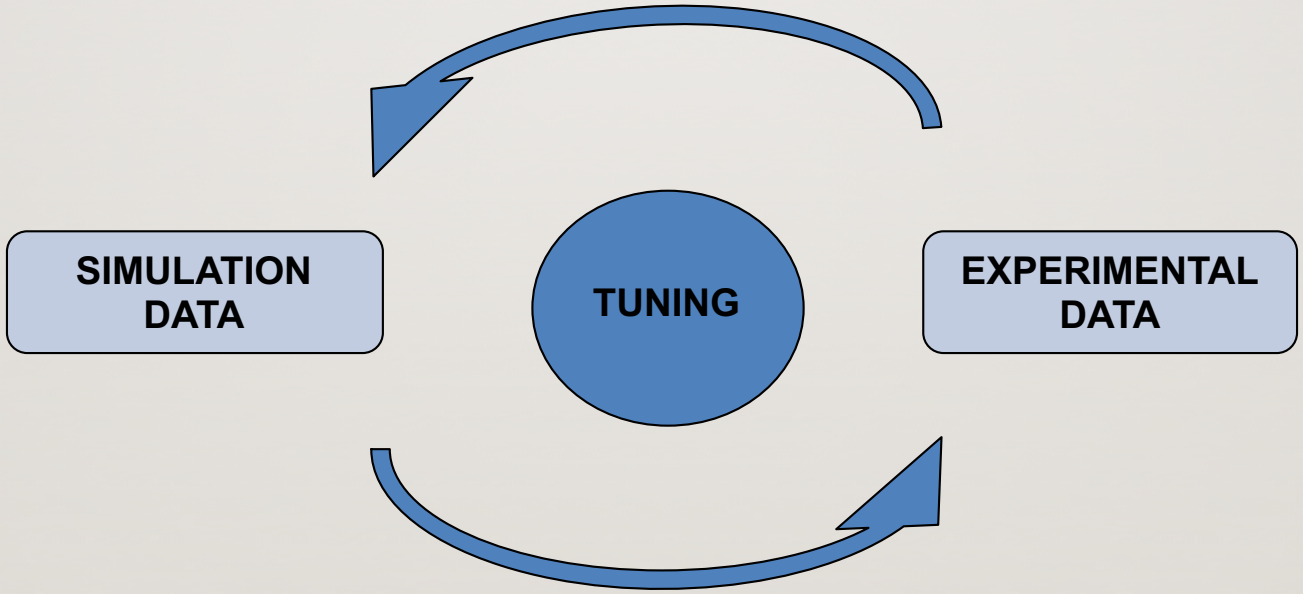
BESIII

- IONIZATION
- DETECTOR GAIN
- ELECTRON DRIFT
- INDUCTION
- ELECTRONICS
- RECONSTRUCTION
- ANALYSIS

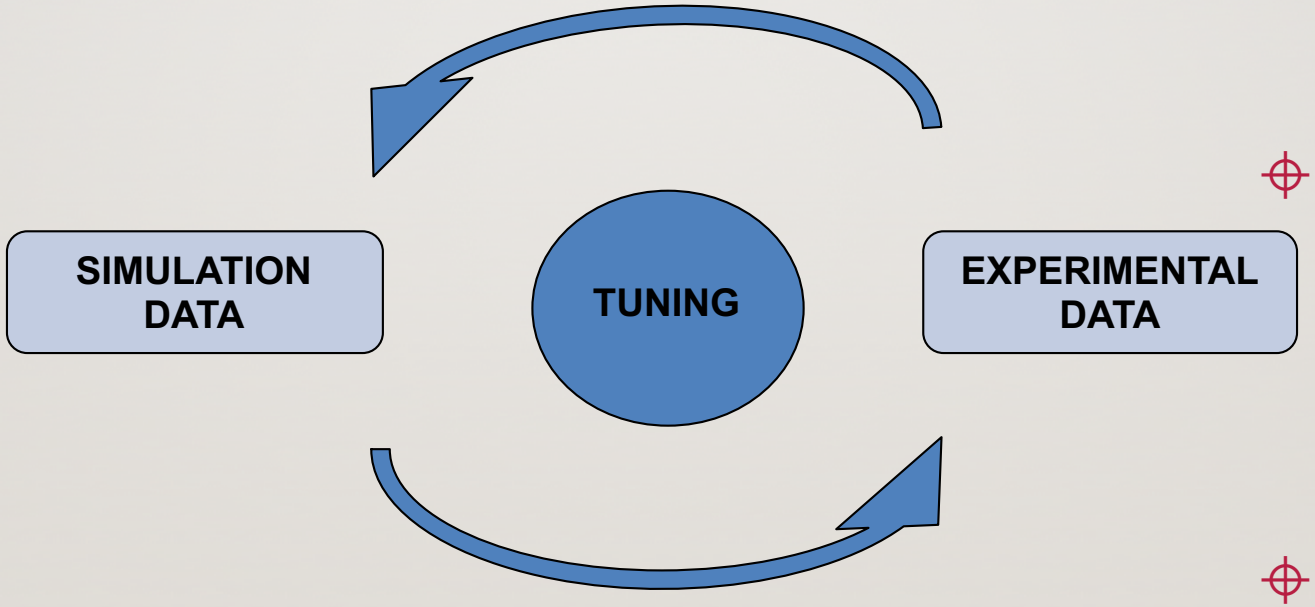
Cremlinplus

- IONIZATION
- DETECTOR GAIN
- ELECTRON DRIFT
- RESISTIVE
- INDUCTION
- ELECTRONICS
- RECONSTRUCTION
- ANALYSIS

DETECTOR RESPONSE PARAMETRISATION



DETECTOR RESPONSE PARAMETRISATION

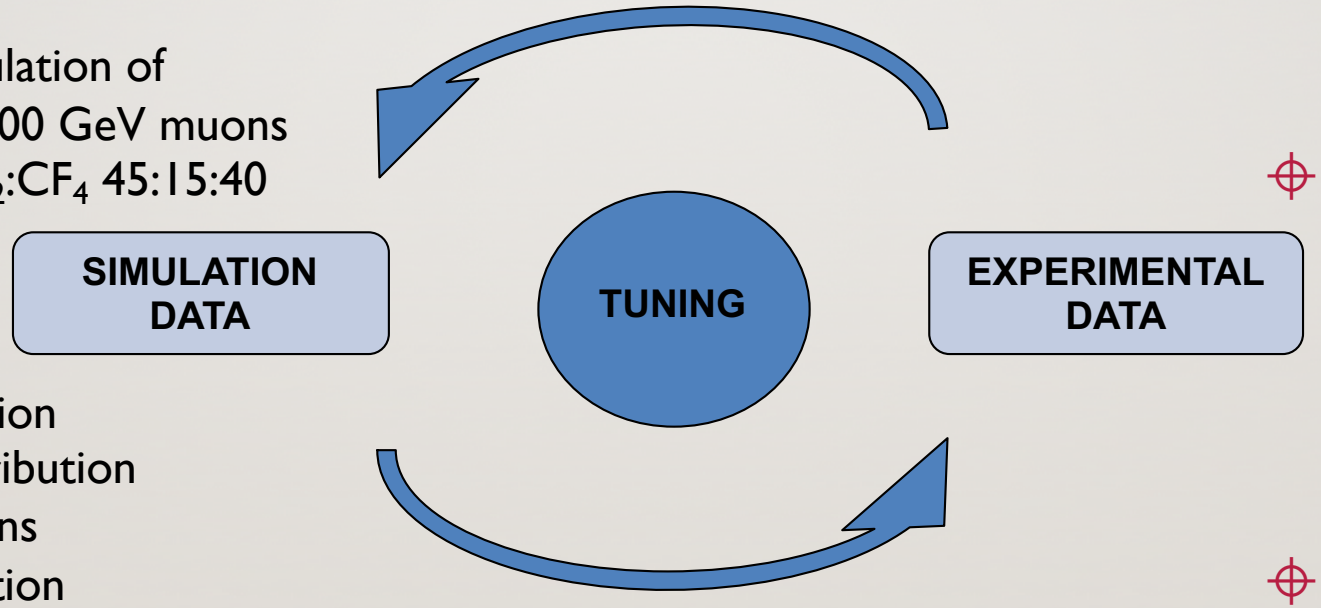


- Start with DATA/MC matching of well known detector configuration to get efficiencies and resolutions.
- Calibrate MC @ $\theta = 0^{\circ}$ and 0.5 kV/cm drift field with cluster size and charge distributions. Validate MC with angle and drift field scans.
- Extrapolate MC to new detector configuration

DETECTOR RESPONSE PARAMETRISATION

- Simulation software developed for BESIII triple-GEM detectors (GTS) → Adapted to μRWELL detector.
- Inputs from Garfield simulation of orthogonal tracks from 100 GeV muons in 6 mm gap with Ar:CO_2:CF_4 45:15:40 and 0.5 kV/cm drift field

i. Primary clusters distribution
ii. Secondary electrons distribution
iii. Space and time resolutions
iv. Gain from Polya distribution



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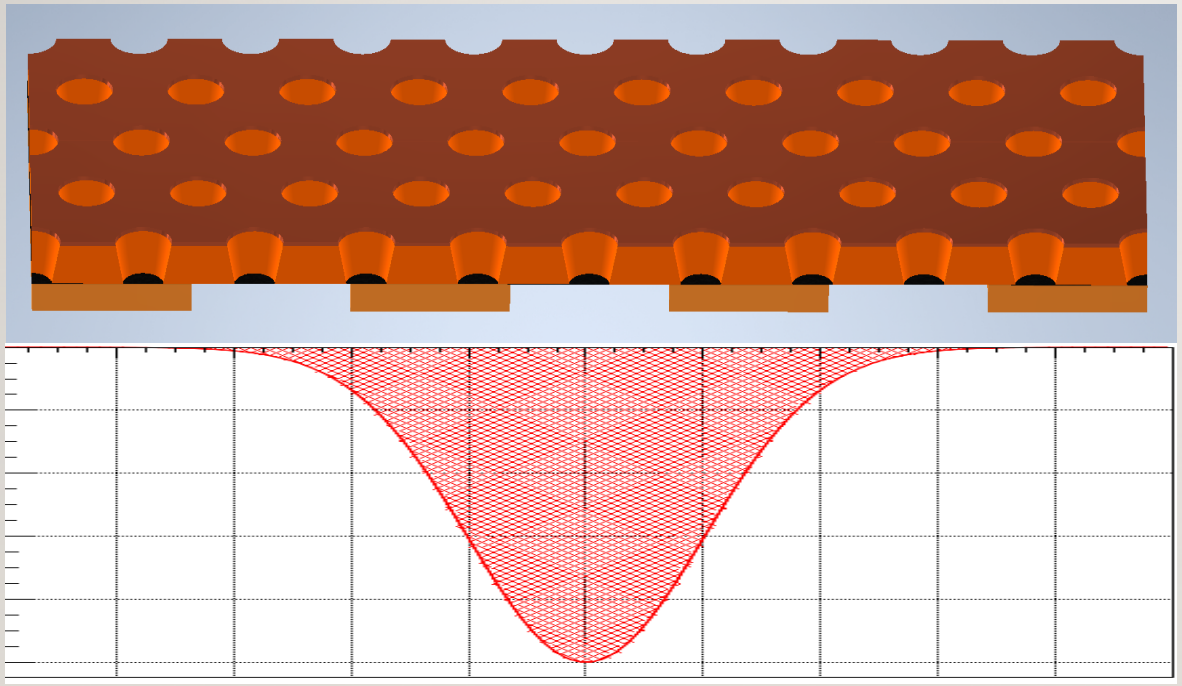
Preliminary distributions for Cluster Size & Charge *without resistive stage simulation* shown @ WP5 GM Sep '20

SIMULATION OF THE RESISTIVE STAGE (I)

Charge spread on the resistive layer been described by M. S. Dixit, A. Rankin,
*NIM **A** 518 (2004) 721-727, NIM **A** 566 (2006) 281-285*



$$\rho(x,y,t) = \frac{N q_e}{2\pi\,(2ht + w^2)} exp\left[-\left(x^2 + y^2\right) / \left(2\,(2ht + w^2)\right)\right]$$

$$\rho(x,t) = \frac{q}{\sqrt{2\pi}\left[\sigma_0\left(1 + \frac{t-t_0}{\tau}\right)\right]} exp\left[-\frac{(x - x_0)^2}{2\sigma_0^2\left(1 + \frac{t-t_0}{\tau}\right)^2}\right] \Theta(t - t_0)$$

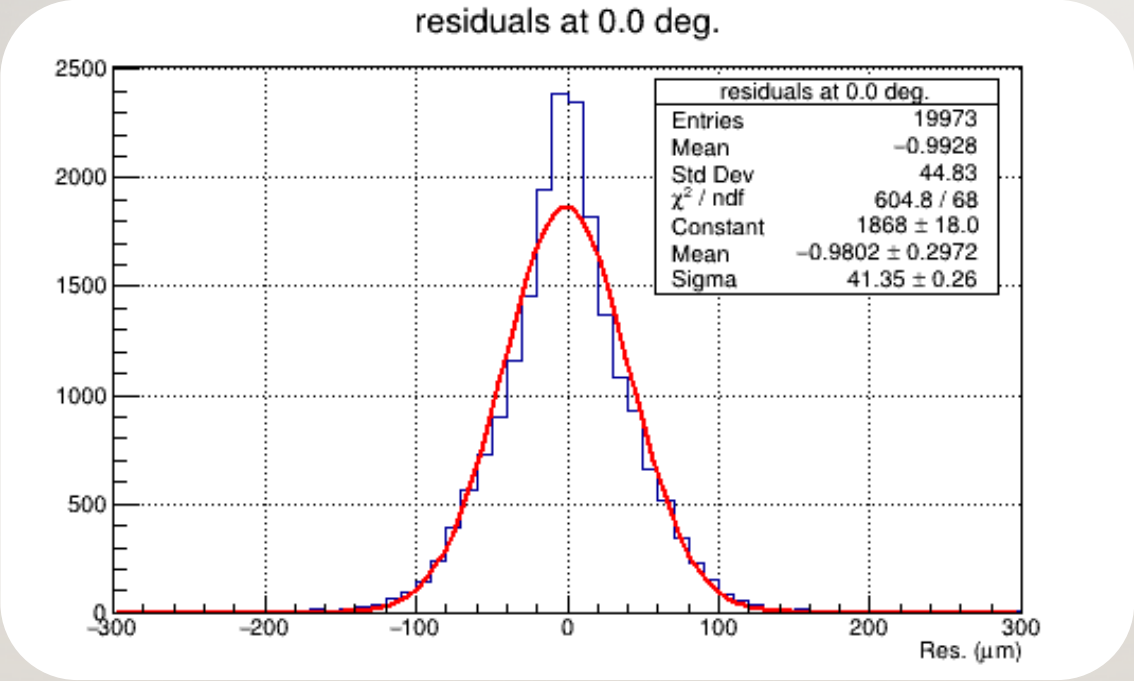
Time-dependent model adapted to a one-dimensional readout

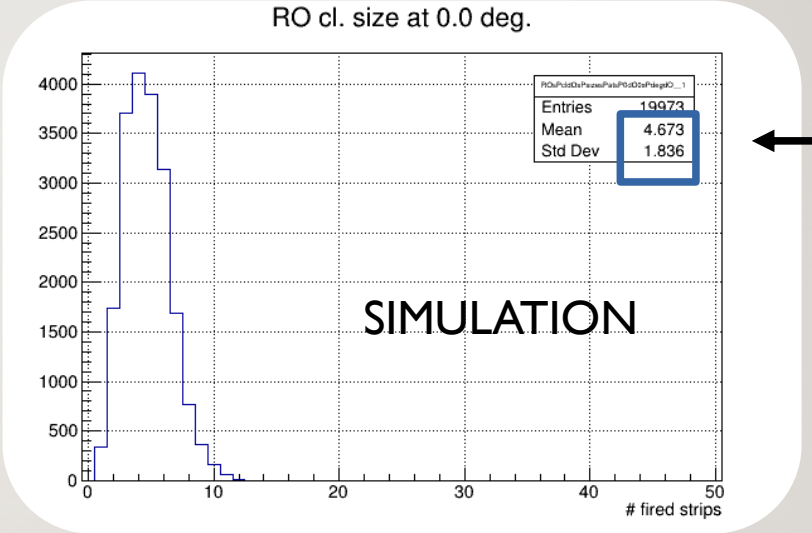
- **q** charge produced in an avalanche
- **x0** position of the primary e- entering the amplification stage
- **σ0** theoretical charge space extension of the avalanche
- **t0** starting time of the track
- **τ** decay time of the charge density due to the electrons movement towards the ground on the resistive surface.

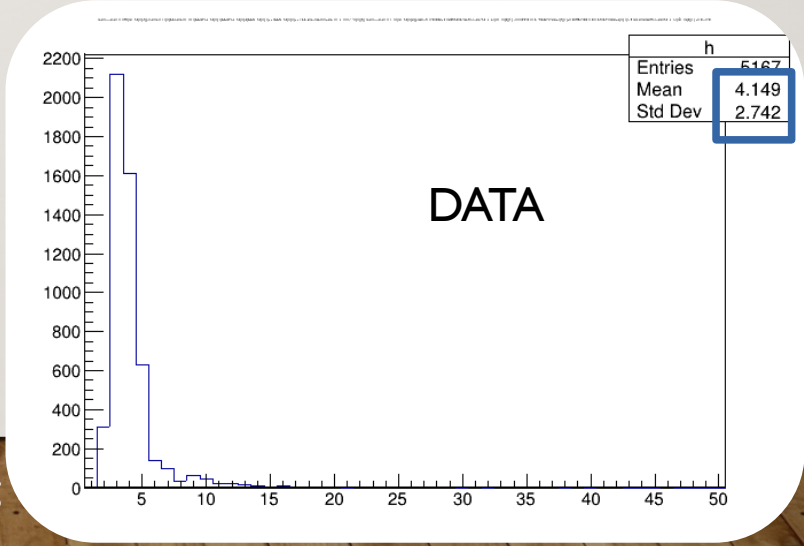
τ is the parameter to be tuned

SIMULATION OF THE RESISTIVE STAGE (II)

- Tuning with tracks at $\theta = 0°$
- Setting $\sigma_0 = 0.001$ cm and $\tau = 5$ ns
- Residuals computed with the Charge Centroid algorithm

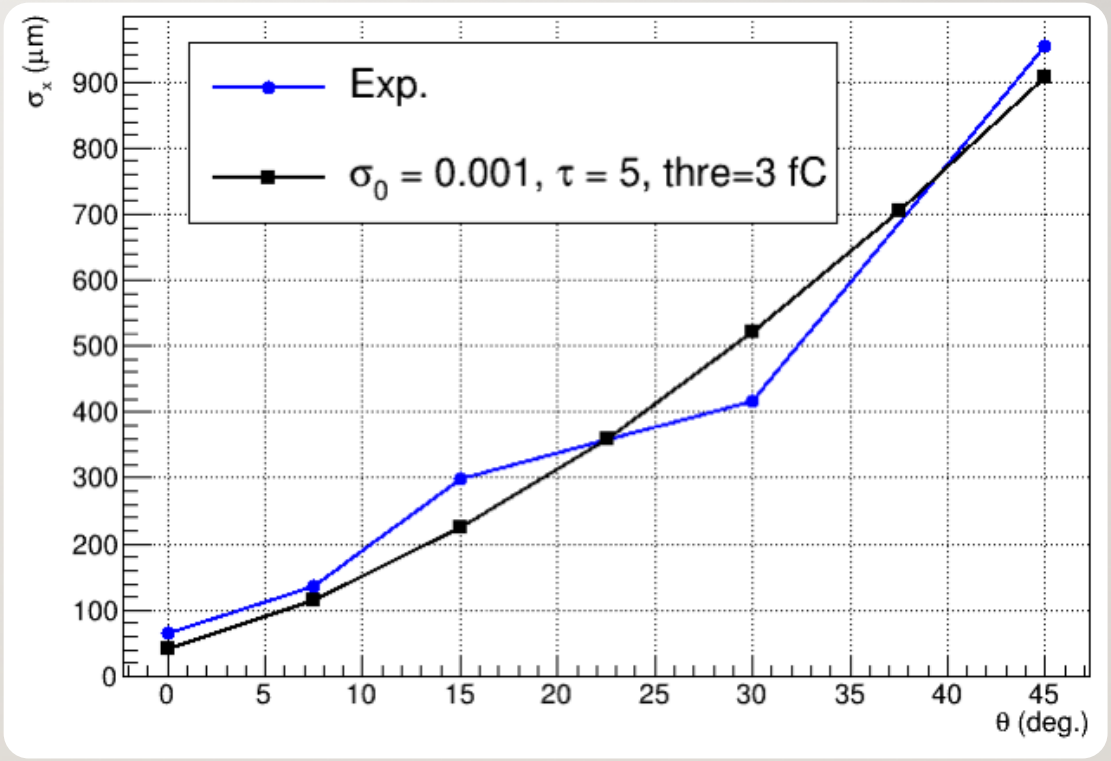






SIMULATION OF THE RESISTIVE STAGE (III)

Spatial resolution σ_x vs θ track incident angle
DATA vs SIMULATION



Next Steps

- Fine tuning of charge spread parameters to fully match experimental cluster size
- Implementation of the μ-TPC method and comparison with experimental data
- Requiring implementation of APV25 electronics in the simulation

CONCLUSIONS (FOLLOWING LUCIE & VITALY'S BULLETED LIST)

Main Achievements

- Inserted 2 small gap B2B C+RWELL detector geometry in DD4HEP framework for SCT detector simulation
- Test & visualization tools passed
- Geant4 Hits generated and saved
- Started soft pion studies: momentum threshold for hits in C+RWELL
- First version of resistive stage simulation ready

Objectives for coming year

- Dedicated readout type for sensitive detector C+RWELL
- Simplified Digitization module
- Detector Response Parametrization: Test & Validate resistive simulation & Insert in DD4HEP framework
- Include Background in simulation studies
- Vertex reconstruction efficiency and resolution

First deliverable and milestone in August 2021 (M18)

- Task 5.3 Status report on the software for the SCT detector.