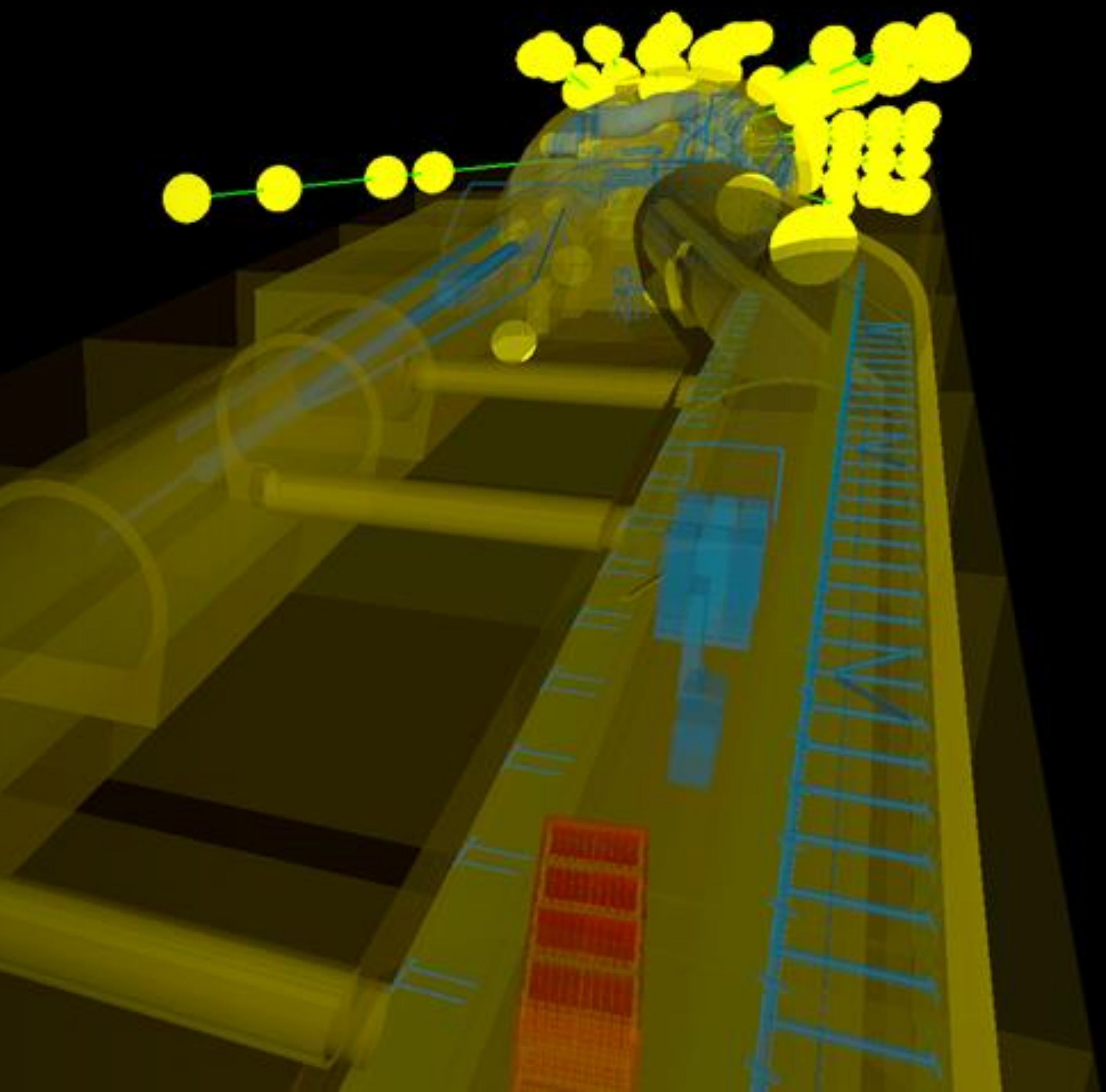
Status of the MoEDAL-MAPP Region GEANT4 simulation, SUMMA



Matti Kalliokoski

Helsinki Institute of Physics

LHCC 155 Week

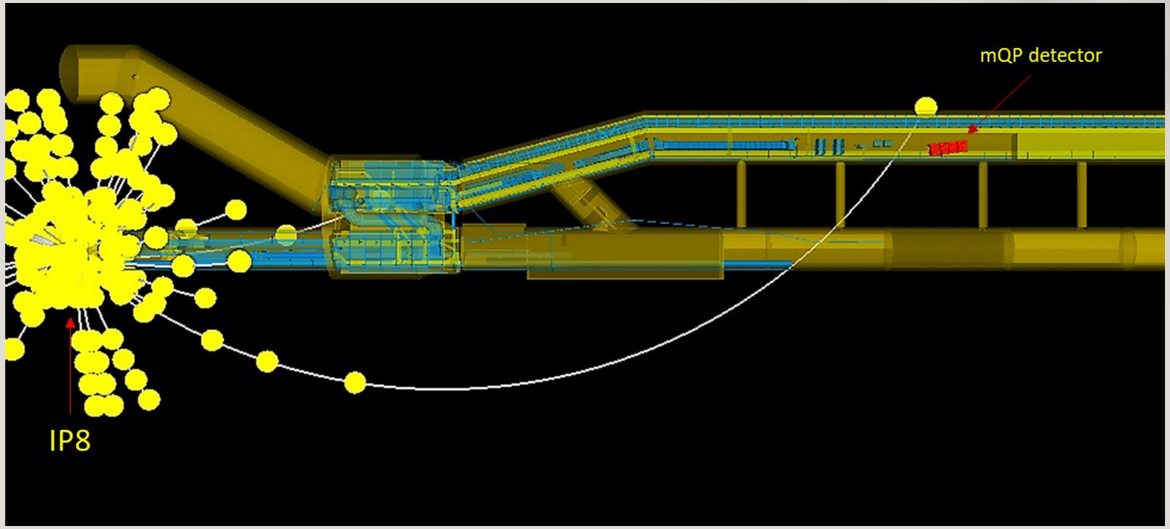
Referee Discusion with MoEDAL-MAPP

MoEDAL Simulation Group

- The simulation group was formed to support simulation studies beyond the LHCb software region
- MAPP extensions, CMS beam pipe studies
- Biweekly meetings to discuss various topics
- 4-5 active members either developing, testing, or running simulations with the software

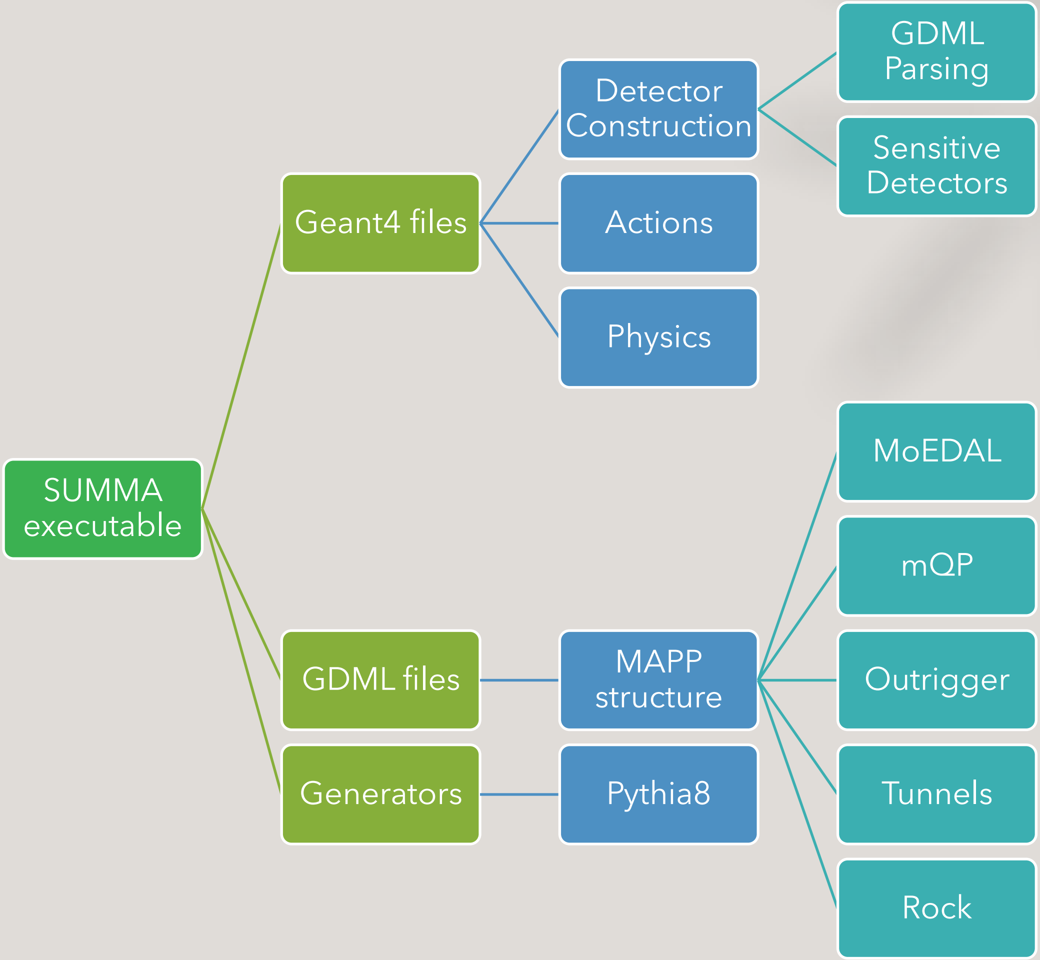
Simulation of the UA83, MoEDAL, MAPP-mCP Arena (SUMMA)

- The MoEDAL simulations are done within LHCb simulation environment Gauss
- However, the MAPP region extends far beyond the IP8
  - It would be difficult to implement the new regions to an LHCb centered environment
  - ⇒ New simulation tool was needed
- The simulation model was built by using standard Geant4 classes to support portability and to reduce the amount of required packages for installations
  - Version 11.0 and above was used, currently on 11.1.1
  - Only two external packages, Xerces-c (for gdml parser) and ROOT (ntuple analysis)
- The code is shared to all MoEDAL-MAPP members through CERN GitLab

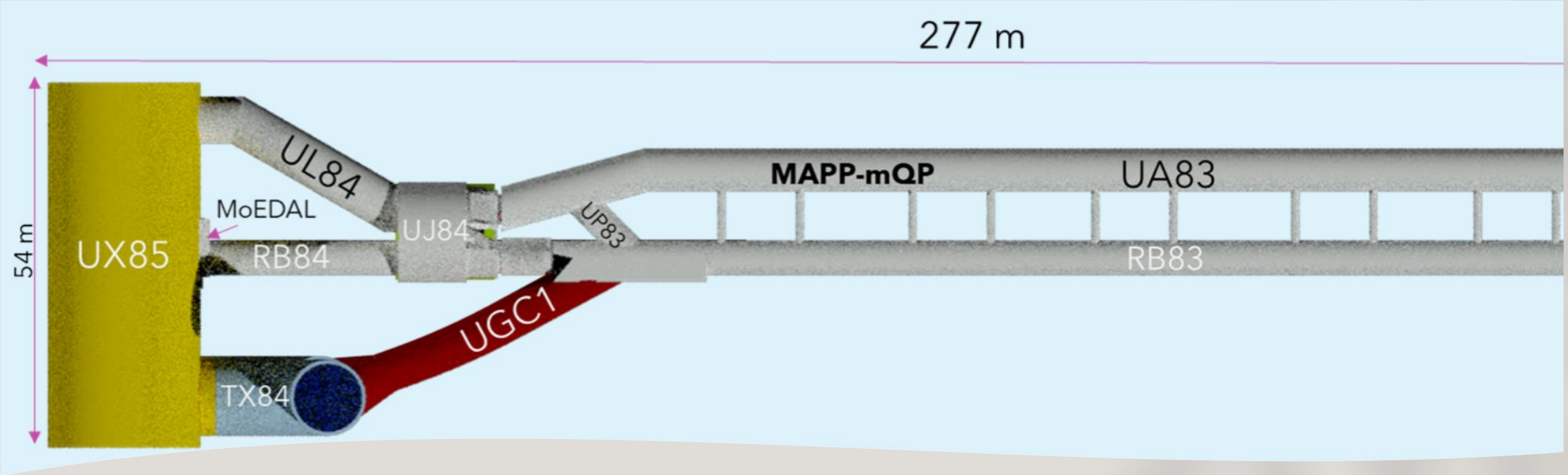


Structure of the software

- The software is divided in tree main parts: Geant4 based classes, GDML model tree and generators
- Geant4 classes control the simulation and allow to utilize user interface
  - Needs to be compiled in order to be run
- GDML files list the geometry structure of the model
  - Allow modifications to elements without need to recompile
- Generators can be run independently to produce input files for the primary generator action in Geant4

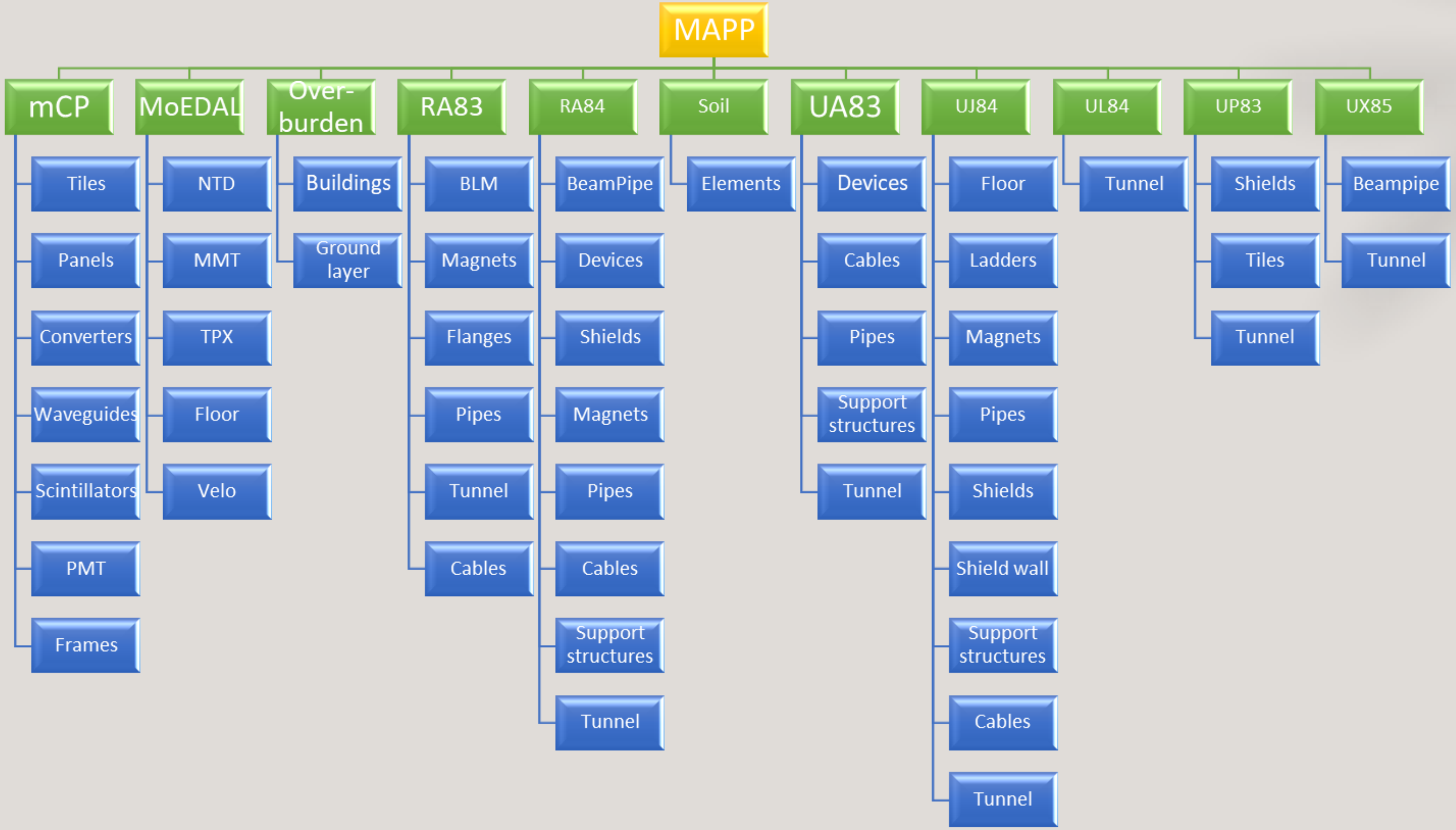


Geometry



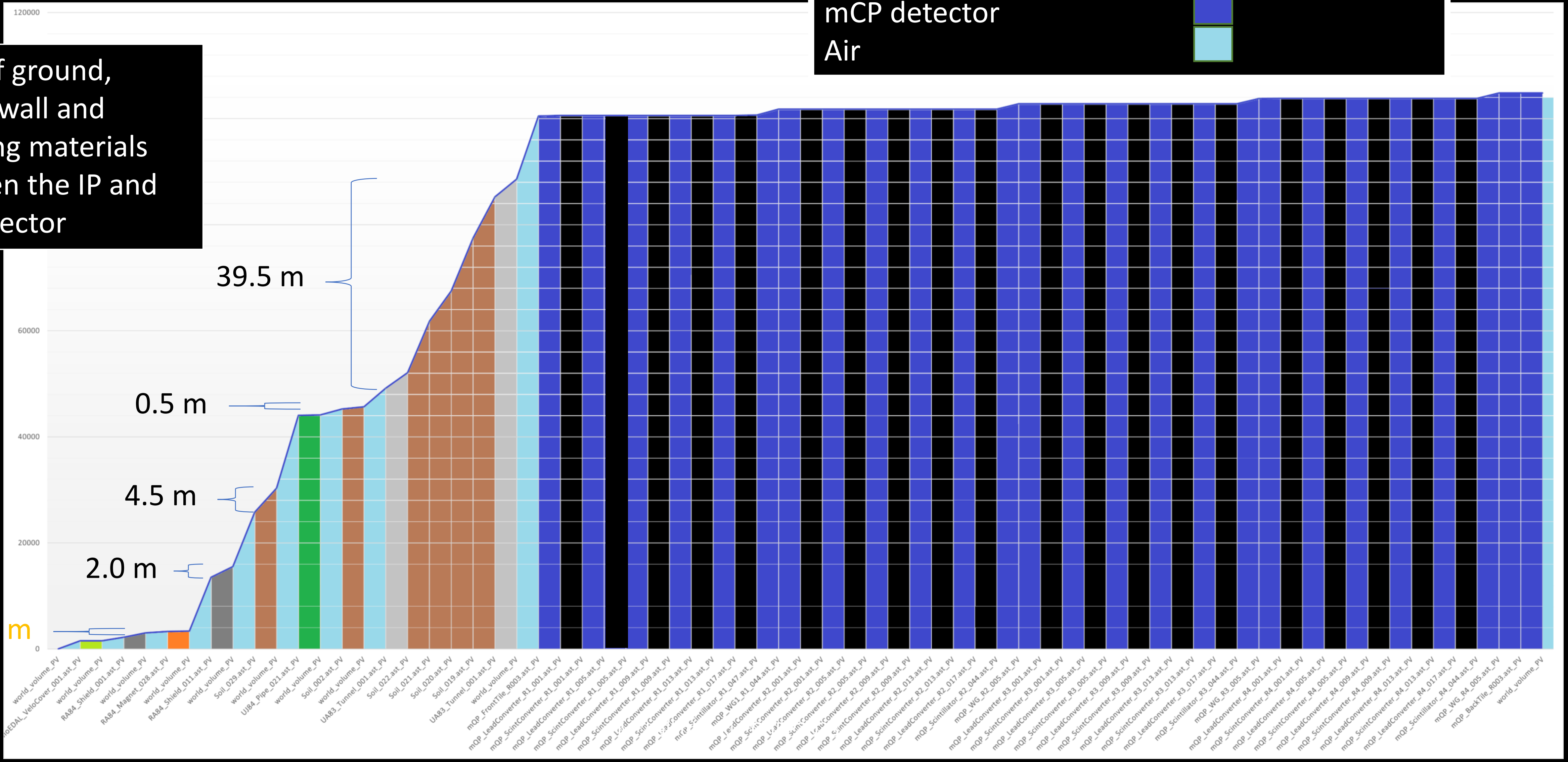
- Construction of the geometry is the slowest part in the model building
- Detailed geometry is based on combination of excavations, mappings, blueprints and CAD drawings
- These are combined into single CAD model to correctly set the coordinate system and mutual positions of the elements
- The geometry is produced through the following steps:
  1. CAD drawings are exported as STP files and split and stored as individual ASCII STL elements
  2. These are read with CAD to GDML converter which creates GDML files
  3. The files are combined under GDML descriptors which are used to generate a complete model tree
  4. The GDML file structure is then read in to Geant4 through G4gdml parser
- The original files cannot have overlaps or undefined elements in order to generate tessellated solids with reasonably small number of vertices

Geometry


MAPP
mCP
Tiles
Panels
Converters
Waveguides
Scintillators
PMT
Frames
MoEDAL
NTD
MMT
TPX
Floor
Velo
Over-burden
Buildings
Ground layer
RA83
BLM
Magnets
Flanges
Pipes
Tunnel
Cables
RA84
BeamPipe
Devices
Shields
Magnets
Pipes
Cables
Support structures
Tunnel
Soil
Elements
UA83
Devices
Cables
Pipes
Support structures
Tunnel
UJ84
Floor
Ladders
Magnets
Pipes
Shields
Shield wall
Support structures
Cables
Tunnel
UL84
Tunnel
UP83
Shields
Tiles
Tunnel
UX85
Beampipe
Tunnel

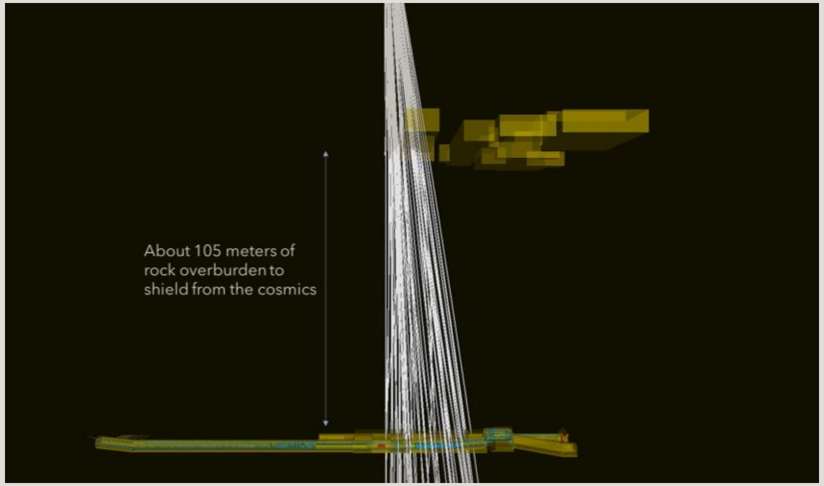
Geometry model

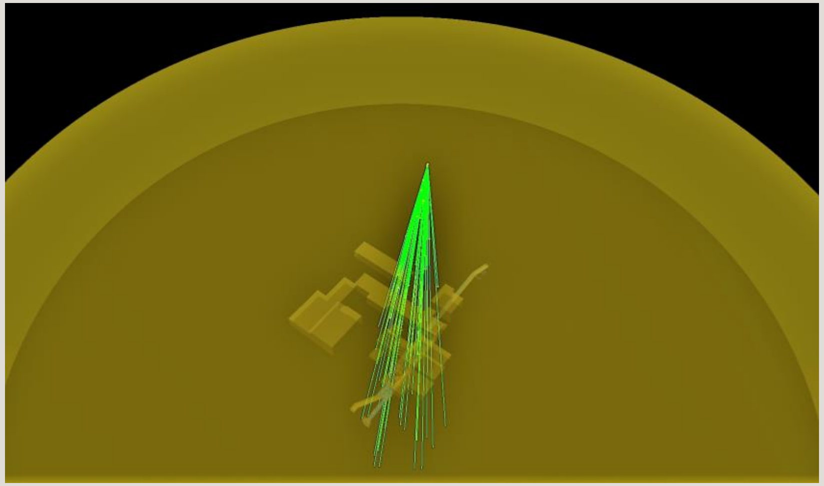
47 m of ground, tunnel wall and shielding materials between the IP and the detector



Overburden

- In addition to the tunnel elements, a layer of about 105 meters thick is implemented in the model
- This layer can be switched off if it is not used
- The overburden is currently modelled as a disk which covers the incoming radiation up to about 45 degree angle
    - The layer can be extended
    - At the moment the higher angles would require extensions to the tunnel models



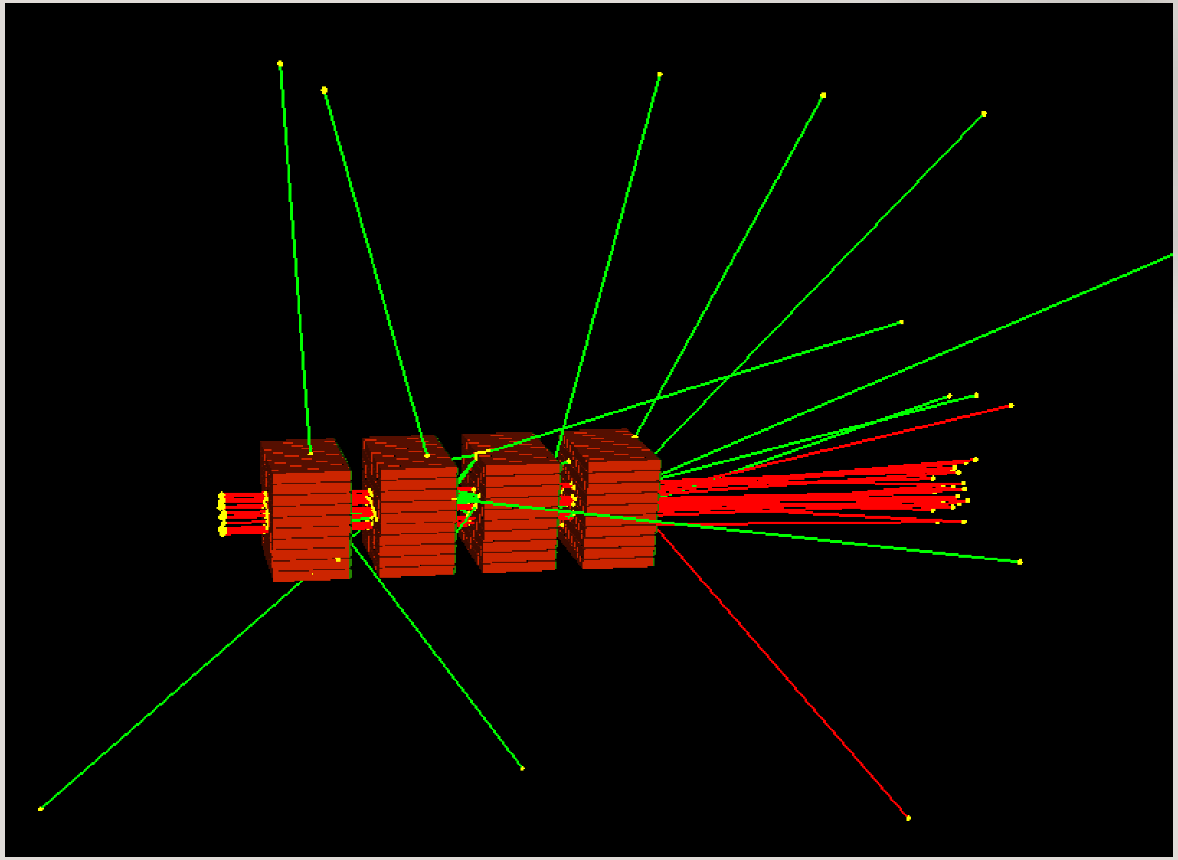


Detector description

- Detector descriptions and materials are inherited from the GDML files
- The GDML structure is read in, but is converted into single level description
  - All elements are directly daughters of the mother volume
- Each element can be made sensitive
  - Can be used to study interesting material regions
- The model does not include optical properties of the materials
  - Can be implemented but not included at the moment to reduce calculation requirements

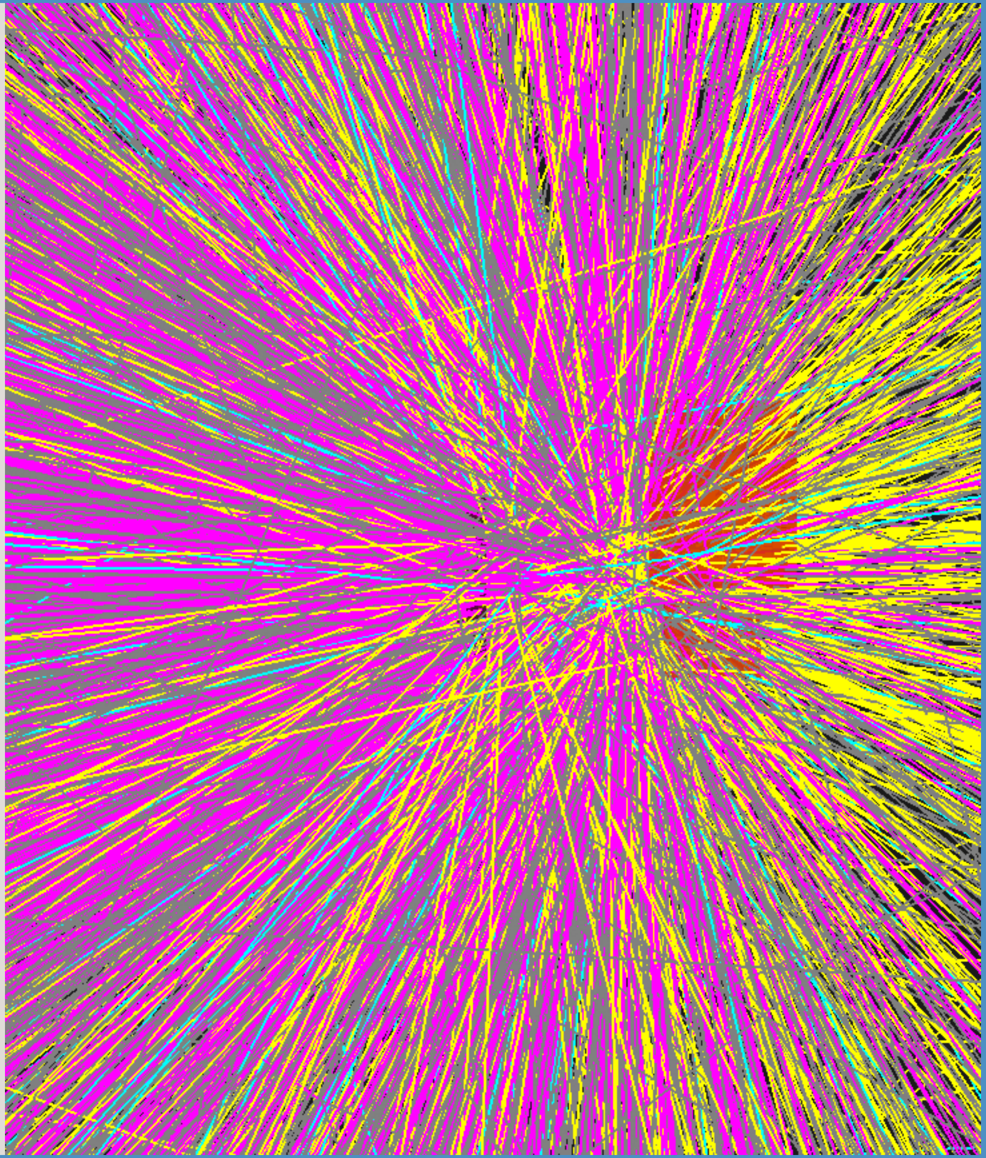
Sensitive detectors

- Two classes which describe the scoring
- Only sensitive detectors generate ntuple files
  - If there are hits in sensitive detectors, a file is generated
  - If no file appears, the detector is not hit
- In the base model, the scintillators of the mCP detector, Outriggers, and MoEDAL NTDs are set sensitive



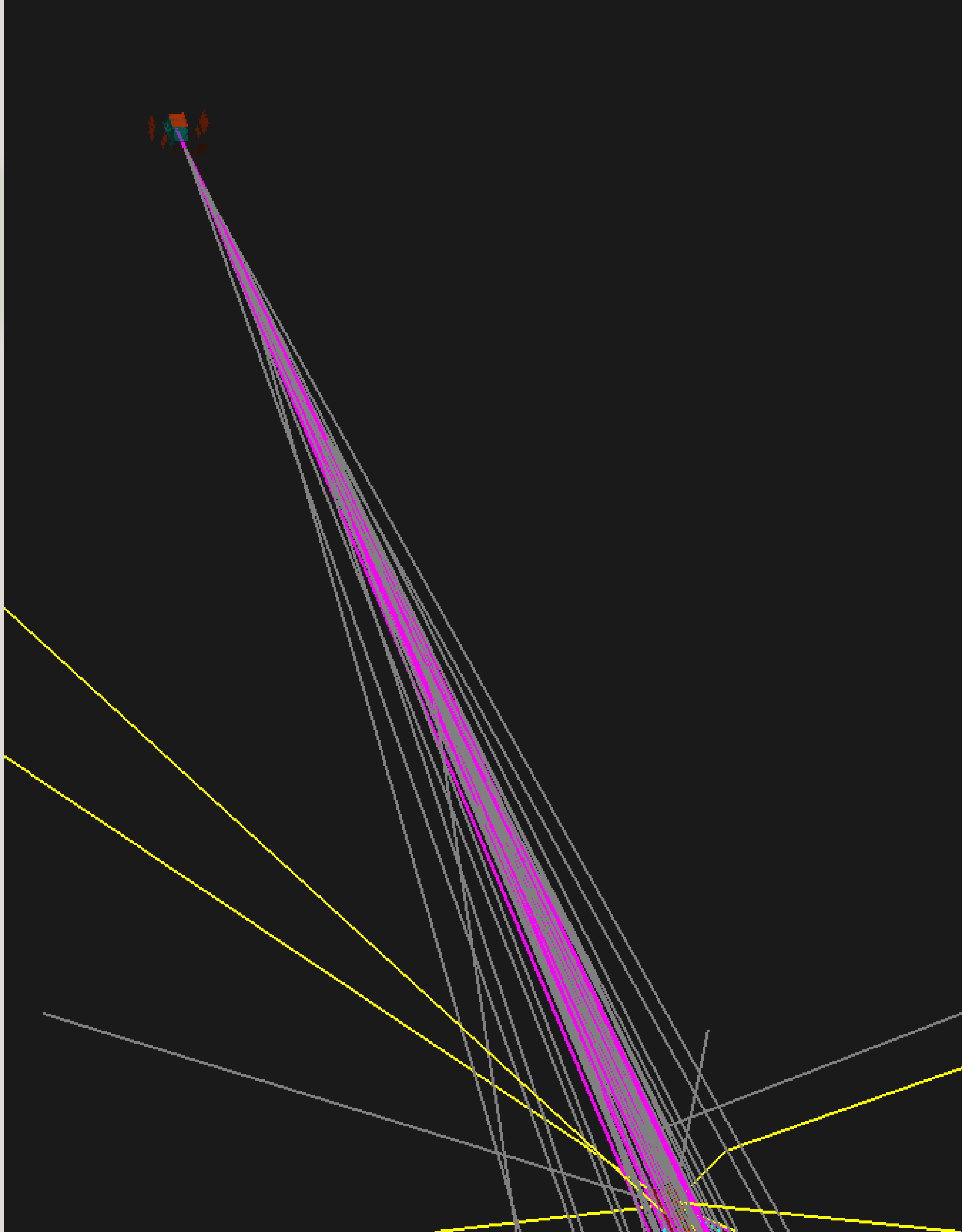
Primary generators

- In basic model the simulations can be run by using Geant4 Particle Gun class
    - Allows to use single type of particle with single energy
    - Can be combined with loops to several particles and energies
- Distributions can be used through General Particle Source class
- More complex input that is generated with e.g. Pythia8 can be read in by using HEPEvt format
    - MUTEX allows parallel processing of single file



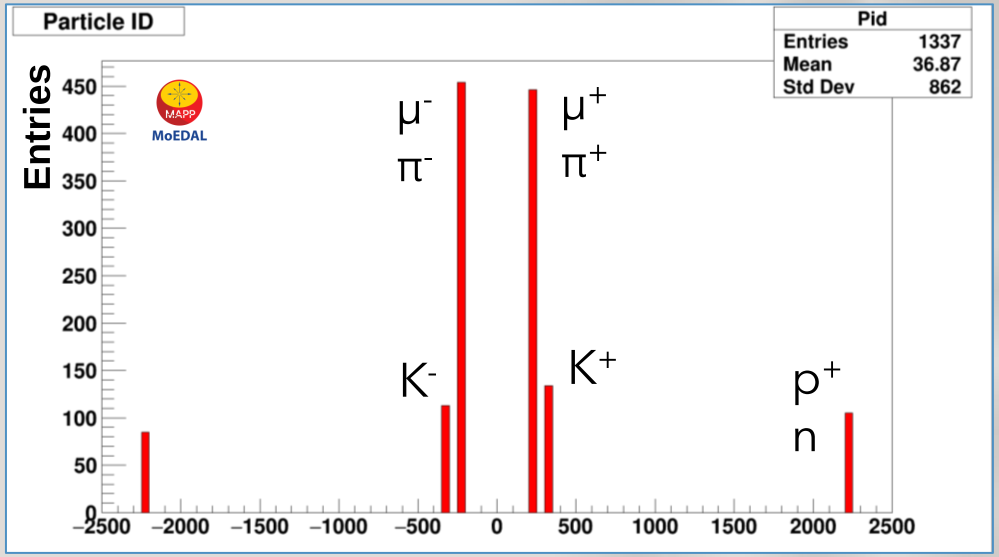
Directional cuts

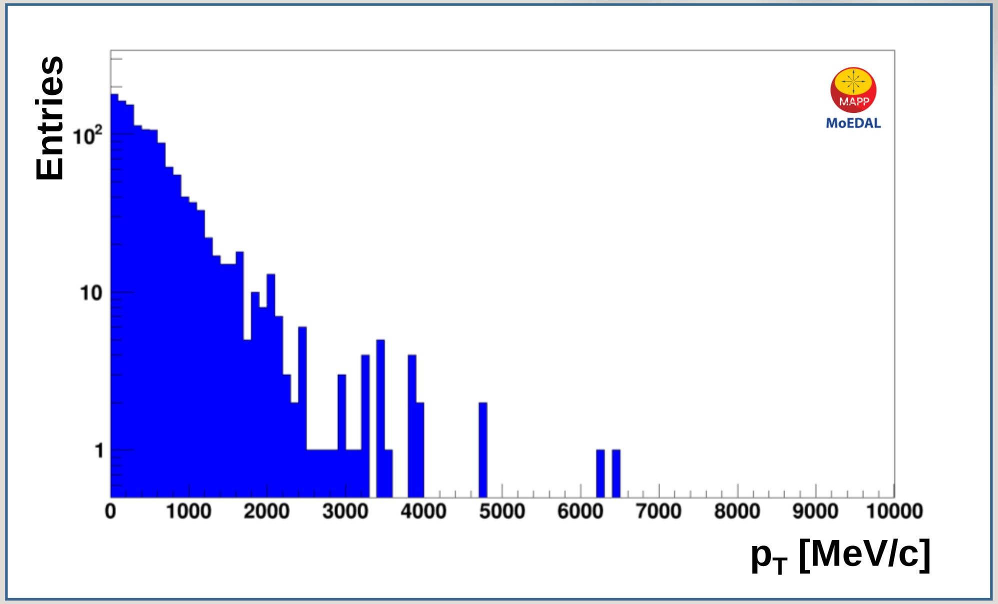
- Pythia8 generates primary vertices with particles for all directions
- For MAPP regions, directions which are not pointing to the detectors waist resources
- Selection cuts can be made by utilizing the locations of the detectors
  - Simple interpolation is used to kill trajectories which would not reach the detectors
  - This will generate a beam cone leaving only the particles which could end up in the detectors
    - User can tune the threshold to allow studies of multiple scattering and secondary productions in the material layers



Background event rate

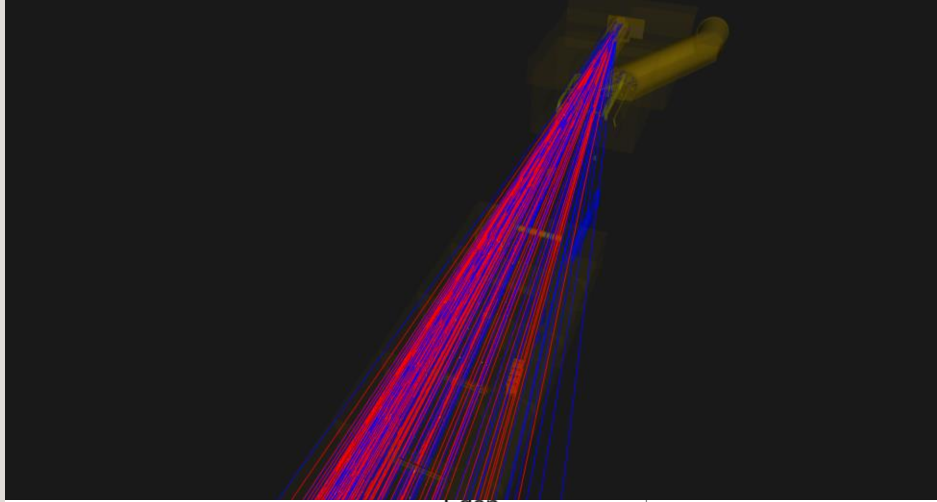
- Main background from the collisions is produced by interactions with muons, kaons and pions from proton-proton collisions
- Also some secondary protons and neutrons are produced in the material budget between the IP and the detectors
- The primary interactions can be produced e.g. with Pythia8
  - From 1×10^7 SoftQCD events generated at the IP we can measure around 1300 events with the mCP detector in UA83
  - For outrigger detectors the rate falls by factor 100

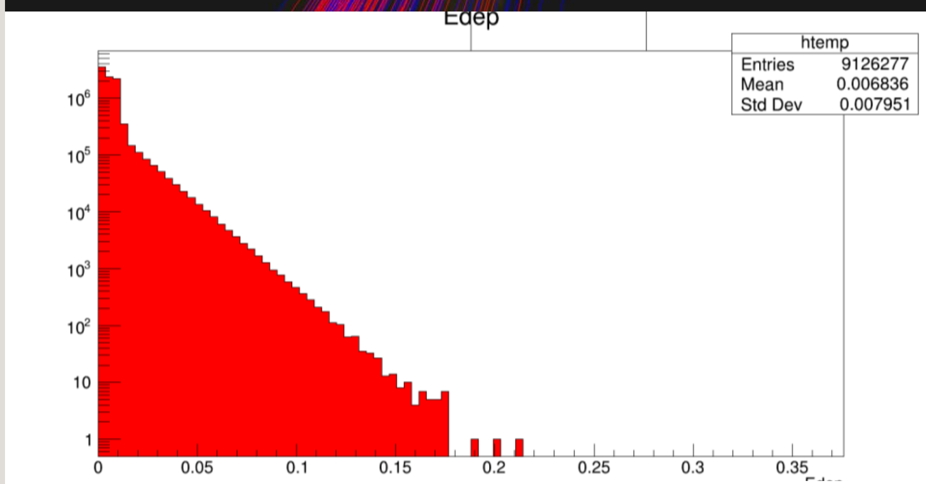


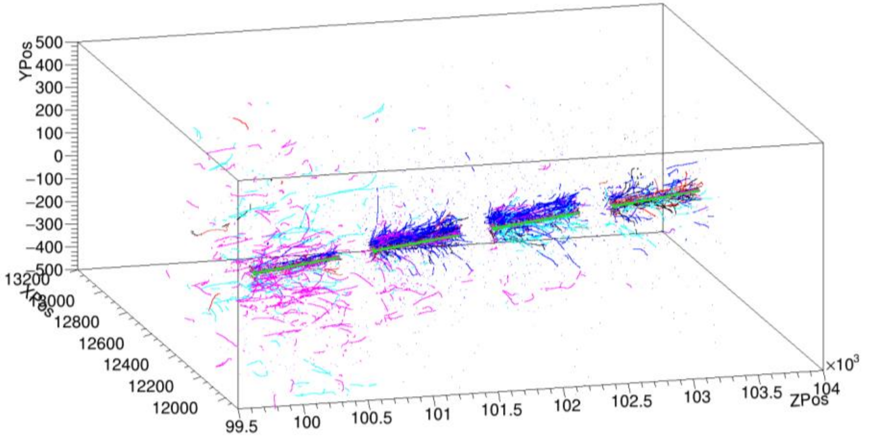


New physics models

- Millicharged particles are introduced through modified physics list
- Since the main loss mechanism of millicharged particles is through ionization and excitation, the model is introduced as an extension to standard electromagnetic model

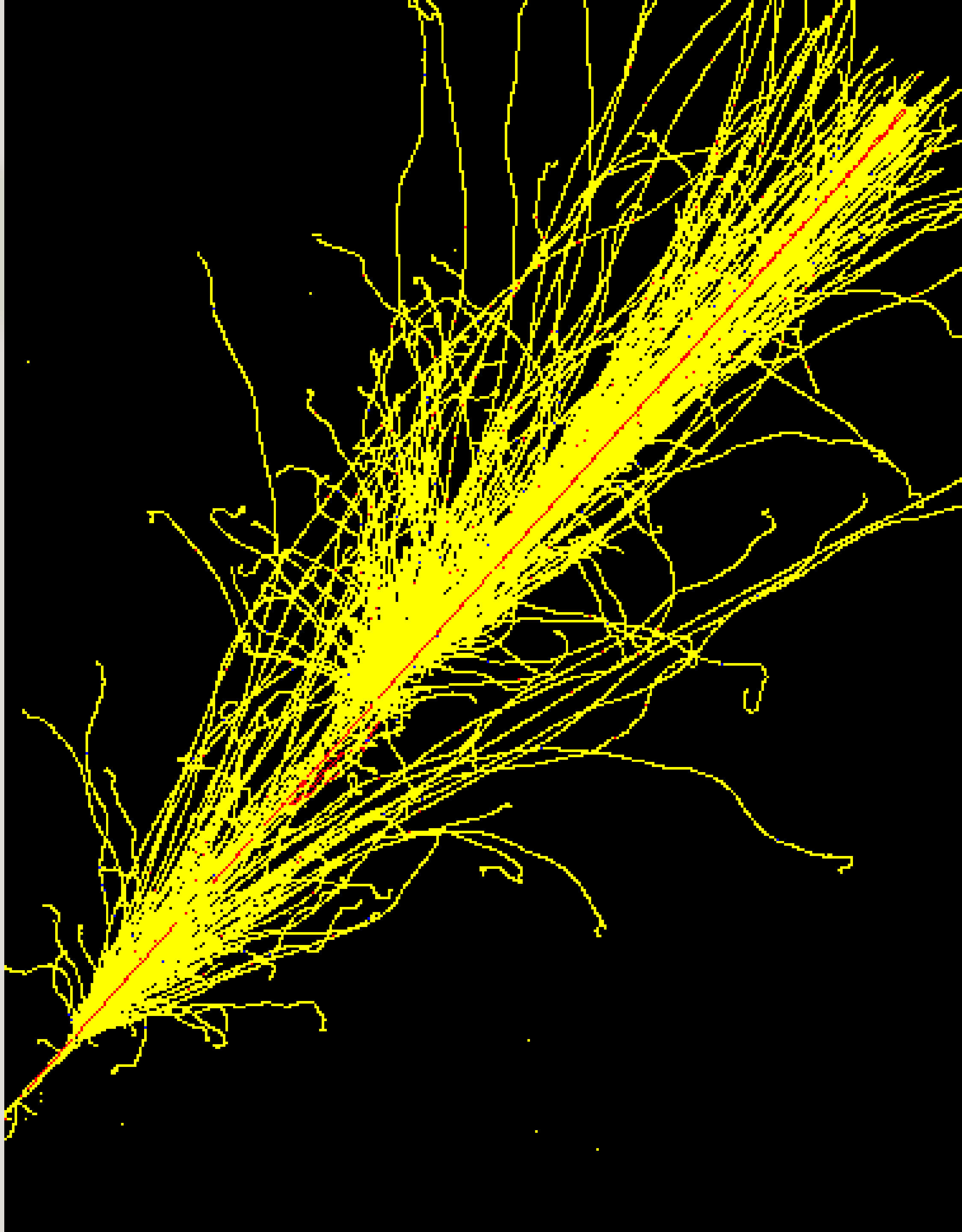






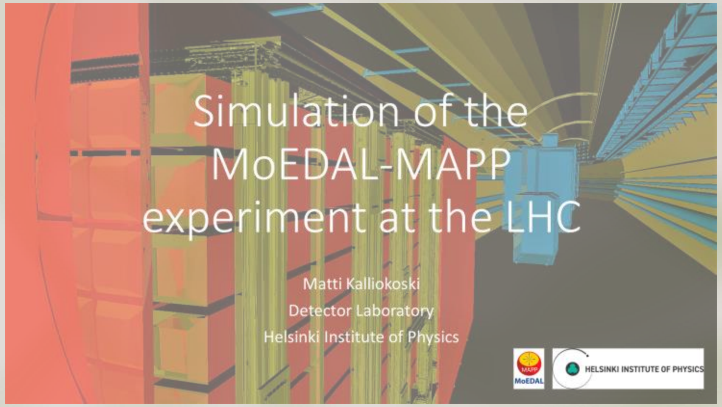
Current status of the model

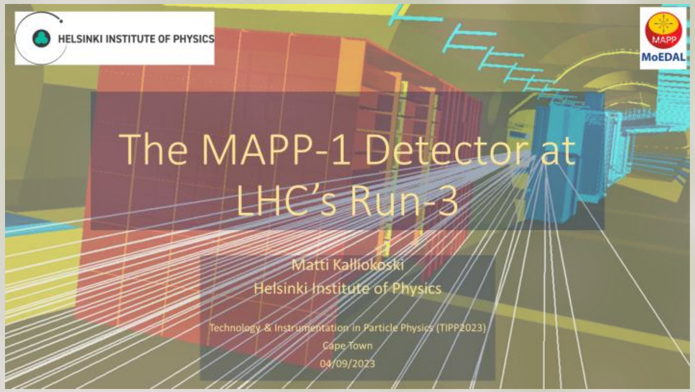
- At the moment each simulation group member are running individual tests
- Bugs and problems in running the code are frequently reported
  - Based on the reports the model is updated and debugged
- New features are implemented by request and to improve the underlying models

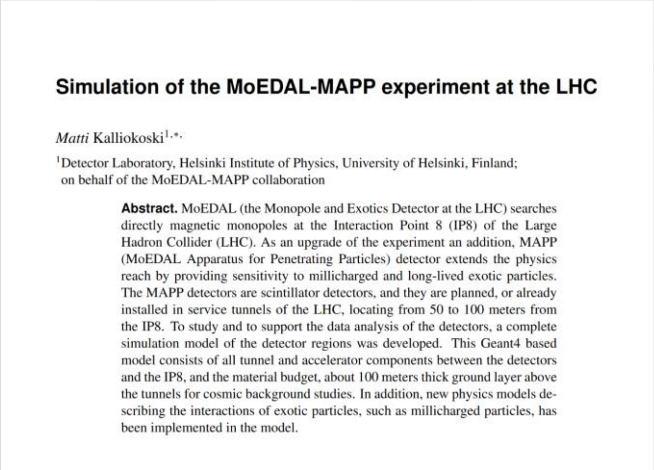


Presentations and Publications

- The model has been presented in CHEP 2023 conference
  - First manuscript is submitted as proceedings
- Some preliminary results have also been reported in TIPP2023
- Manuscript discussing the full model and first results will be finalized and submitted by the end of this year







Simulation of the MoEDAL-MAPP experiment at the LHC

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Abstract. MoEDAL (the Monopole and Exotics Detector at the LHC) searches directly magnetic monopoles at the Interaction Point 8 (IP8) of the Large Hadron Collider (LHC). As an upgrade of the experiment an addition, MAPP (MoEDAL Apparatus for Penetrating Particles) detector extends the physics reach by providing sensitivity to millicharged and long-lived exotic particles. The MAPP detectors are scintillator detectors, and they are planned, or already installed in service tunnels of the LHC, locating from 50 to 100 meters from the IP8. To study and to support the data analysis of the detectors, a complete simulation model of the detector regions was developed. This Geant4 based model consists of all tunnel and accelerator components between the detectors and the IP8, and the material budget, about 100 meters thick ground layer above the tunnels for cosmic background studies. In addition, new physics models describing the interactions of exotic particles, such as millicharged particles, has been implemented in the model.