INFN Istituto Nazionale di Fisica Nucleare

Laboratory for Underground Nuclear Astrophysics

SimLUNA: a new simulation tool based on Geant4 for LUNA experiment

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on behalf of LUNA Collaboration
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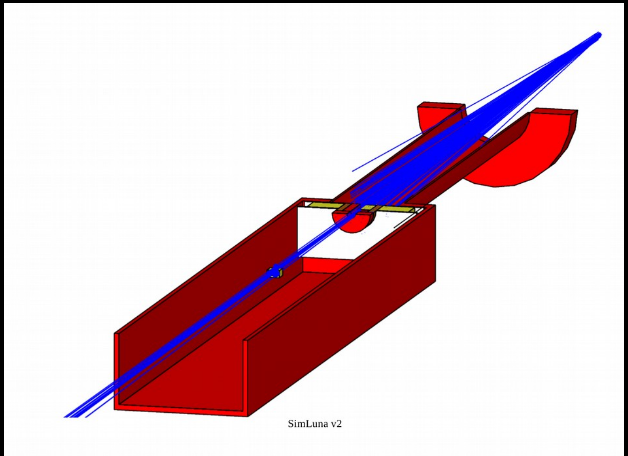
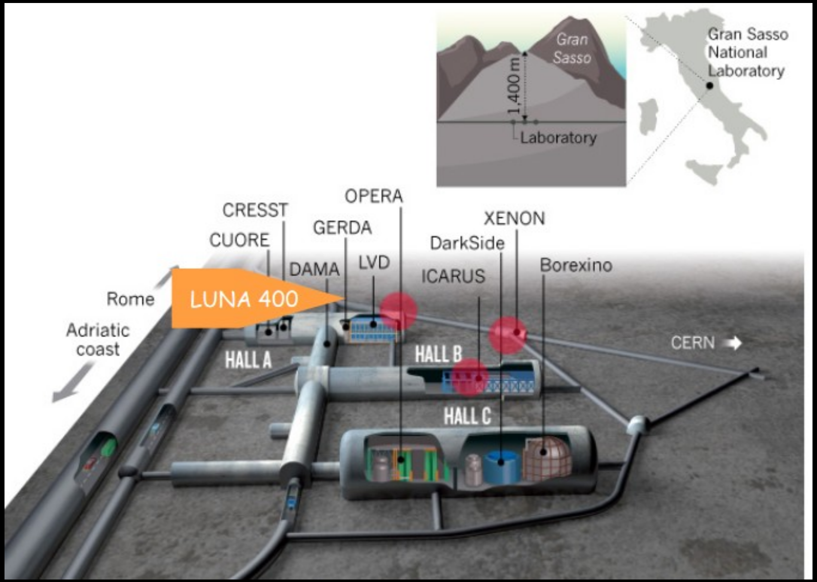
(4) Institute for Nuclear Research (Atomki), Hungary
(5) GSSI-INFN (LNGS)

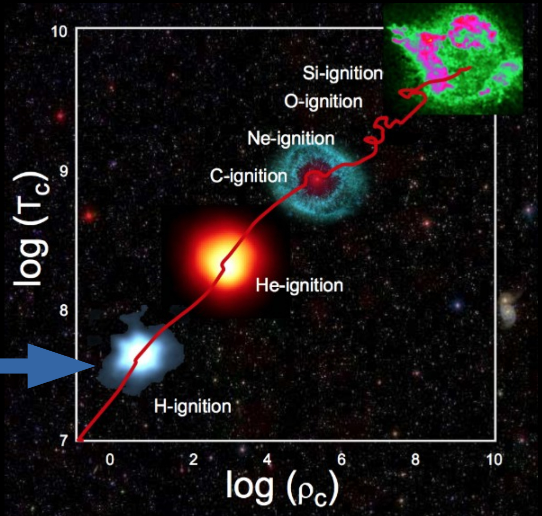


Laboratory for Underground Nuclear Astrophysics

The LUNA facility inside the Laboratori Nazionali del Gran Sasso in central Italy. The site is shielded against cosmic rays by a rock cover - 1400 m thick equivalent to ~ 4000 m water - suppressing the muon and neutron fluxes by six and three orders of magnitude, respectively.

Nuclear fusion is the engine of stars: it produces the energy that stabilizes them against gravitational collapse and makes them shine. LUNA measures the reactions cross sections.





For a 15 M_{sun} star:

Reaction	Timescale
Hydrogen burning	10 million years
Helium burning	1 million years
Carbon burning	300 years
Oxygen burning	200 days
Silicon burning	2 days

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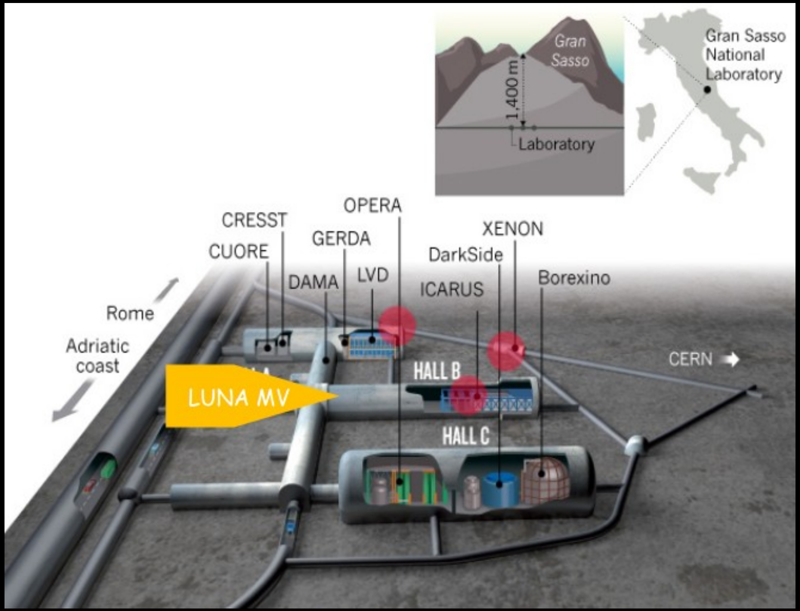


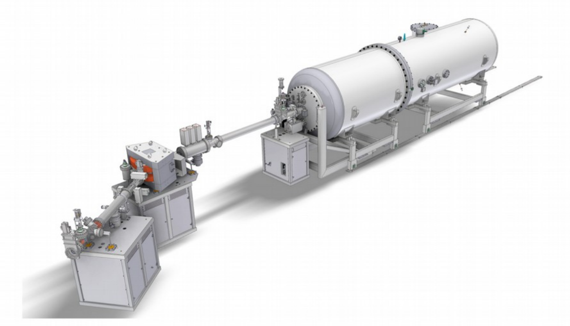
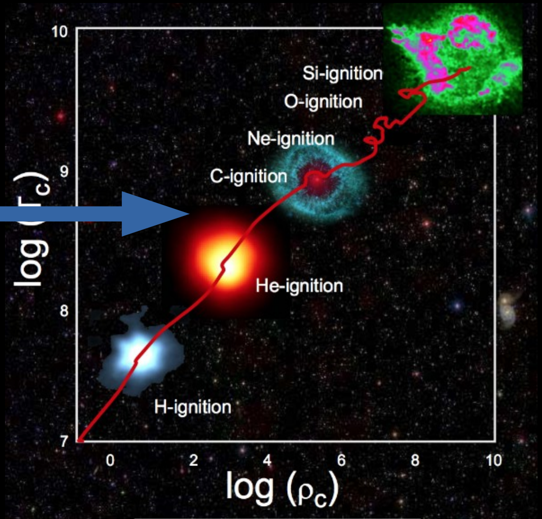


Fig. 1. 3D-CAD layout of the LUNA-MV Singletron system.



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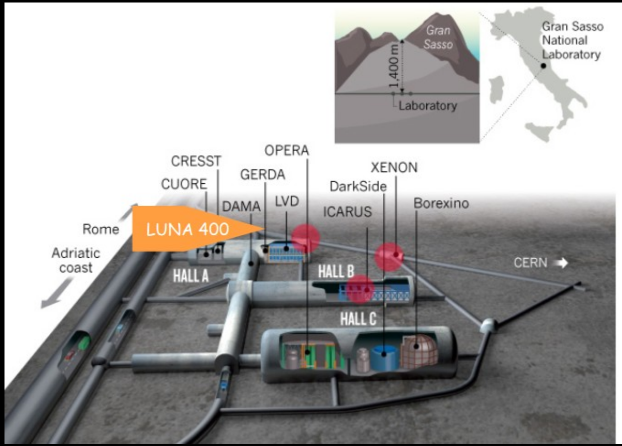
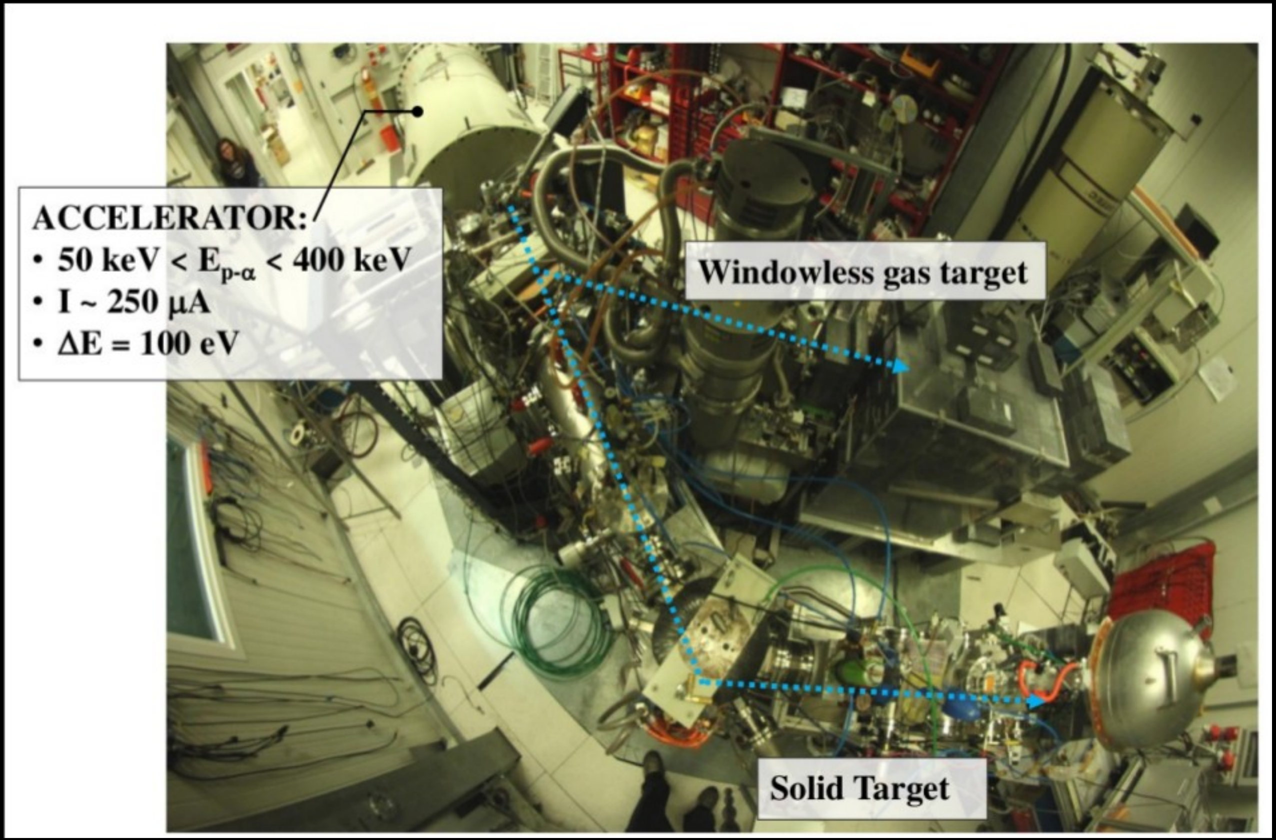


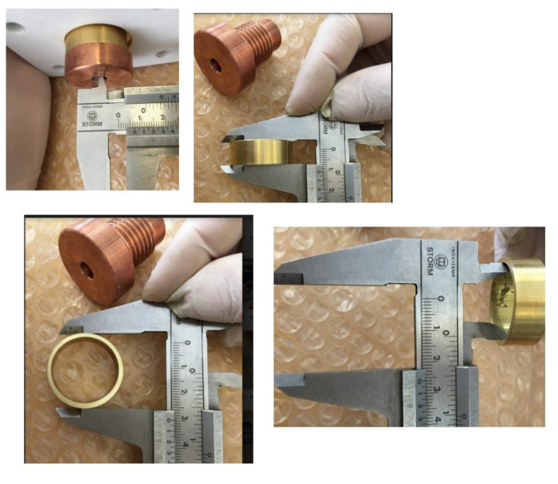


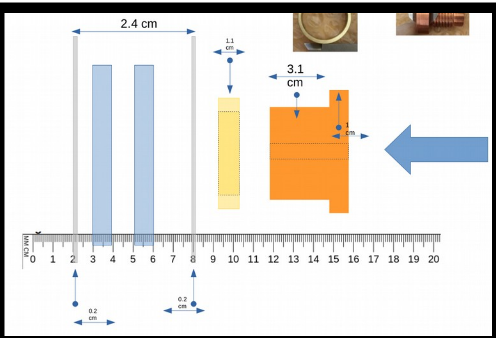
SimLuna

- Goal: to have one common MC software based on Geant4 for LUNA experiment
- Major advantages:
  - One “trusted” version of the software:
    - Experimental setups (reaction chambers / shielding / detectors) validated and then released in SimLuna software - available to the collaboration
    - User not need to download and build the software on his laptop, he can modify settings via external scripts
    - Massive MC production using LNGS clusters
    - “Repository” of the MC studies
    - Modular → Elements of the setups “called” when needed
- Several setups already implemented and in phase of validation: D(p,g)^{3}He, ^{20}Ne(p,γ)^{21}Na, neutron absorption..
- Script for “on line visualization” (Dawn + DawnCut)

SimLuna

- $^{20}Ne(p,\gamma)^{21}Na$: reaction chamber + collimator (layer x 2 teflon, copper “screw”, brass ring, brass layers) + detector (HPGe)
- Two running option: radioactive source / reaction





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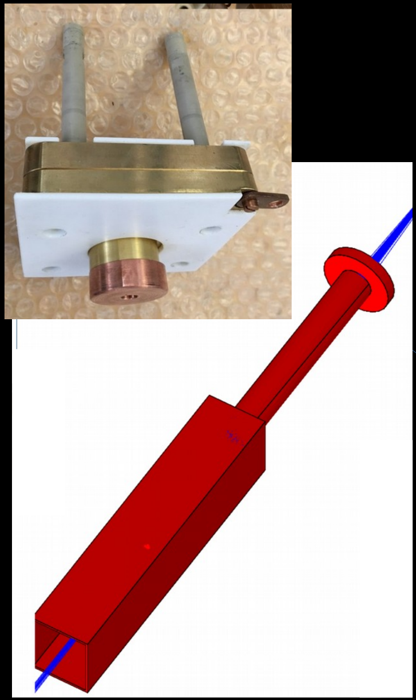
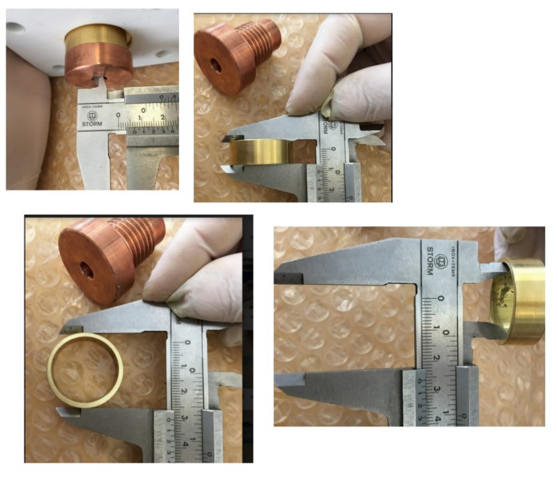
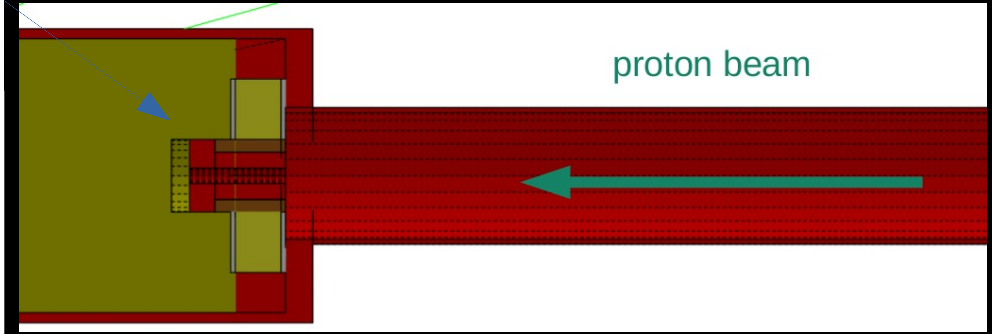
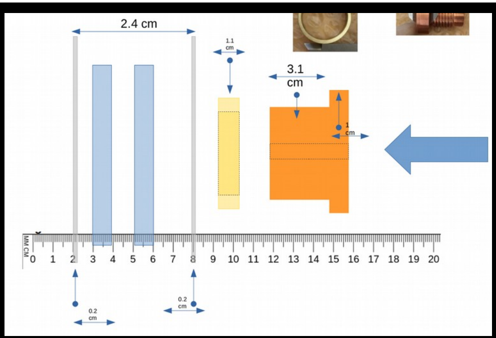


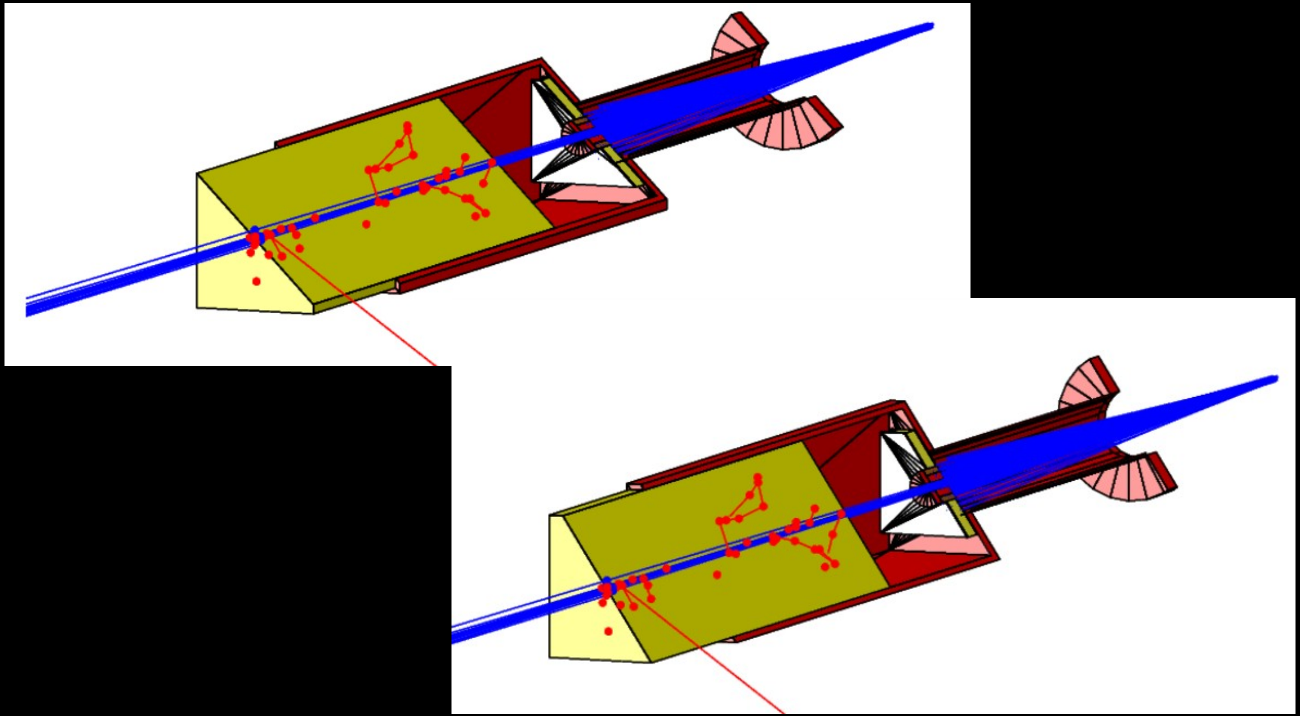


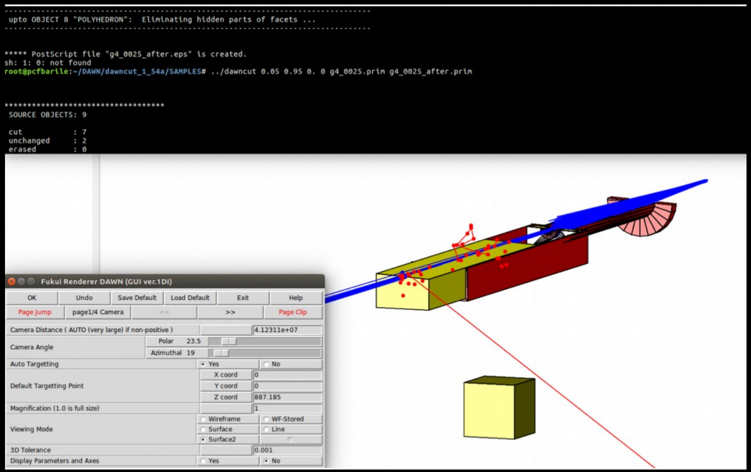




SimLuna

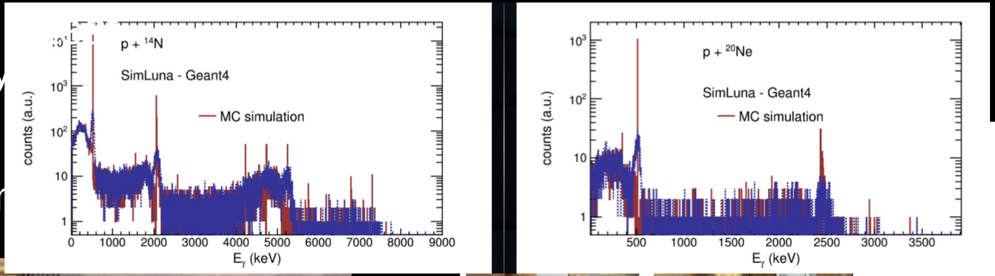
- Goal: to have one common MC software based on Geant4 for LUNA experiment
- Script for “on line visualization” (Dawn + DawnCut): DawnCut is used to modify the *.prim file before drawing it with DAWN. It removes certain sections to produce cut views of your geometry

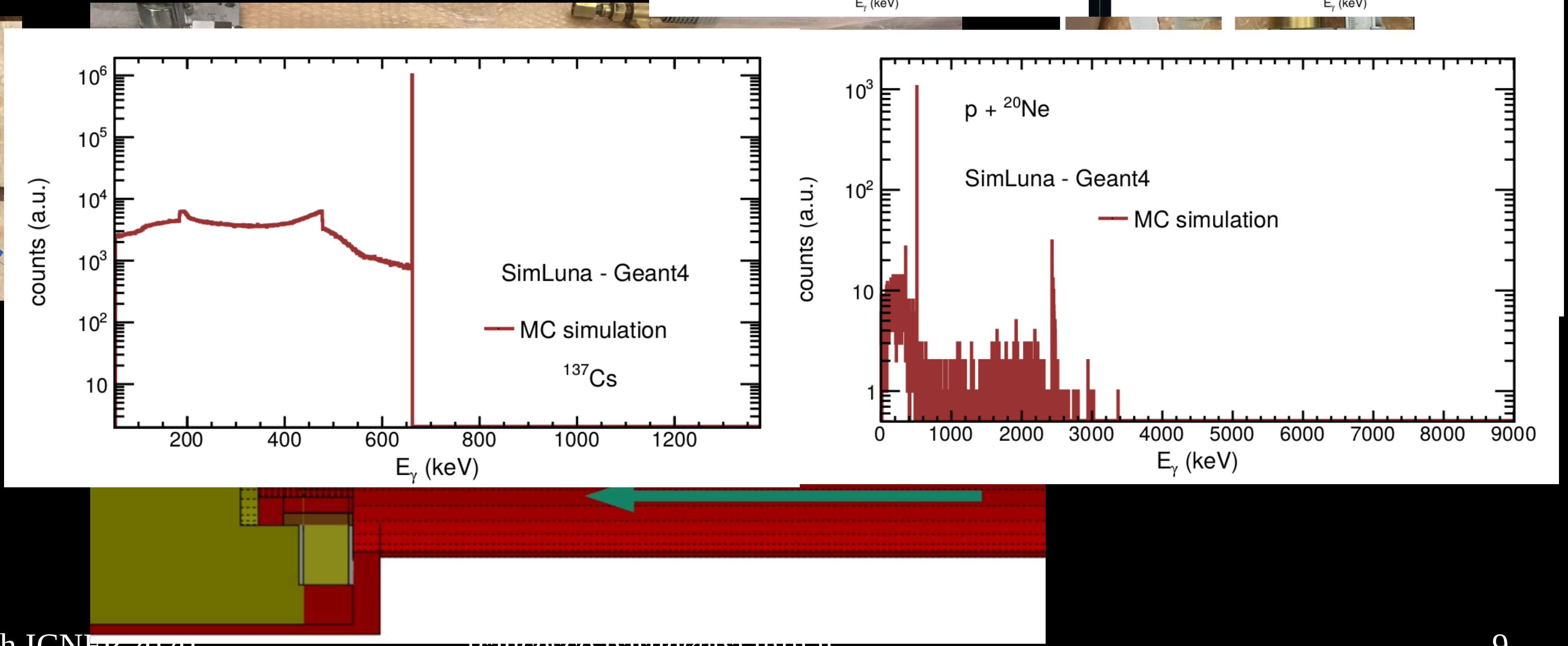




SimLuna

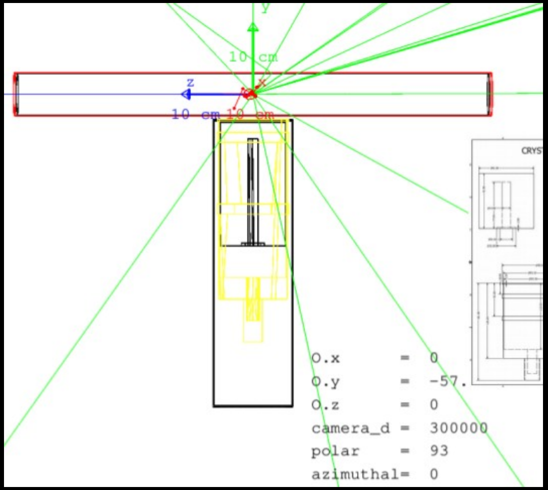
- $^{20}Ne(p,\gamma)^{21}Na$: reaction chamber + collimator (lay
  + detector (HPGe)
- Two running option: radioactive source / reaction



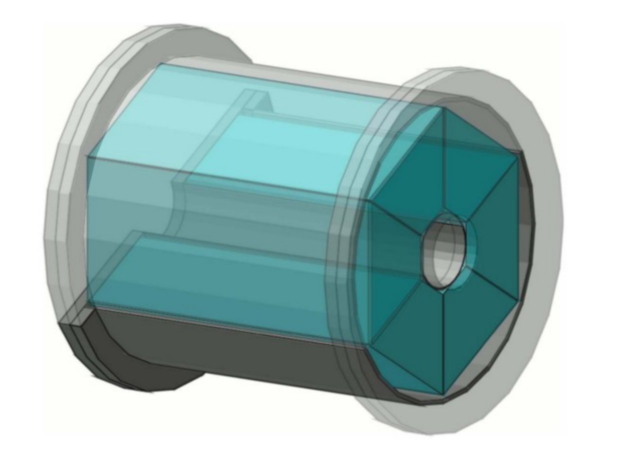


SimLuna

- D(p,γ)^{3}He: reaction chamber + detector (HPGe)
- Two running option: radioactive source / reaction

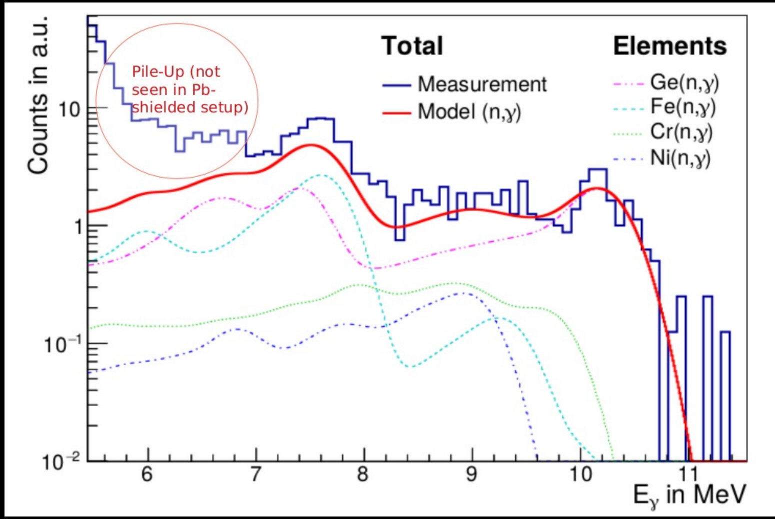


Neutron absorption



BGO ($Bi_4Ge_3O_{12}$, BGO)

BGO detector used at LUNA (Geant4)



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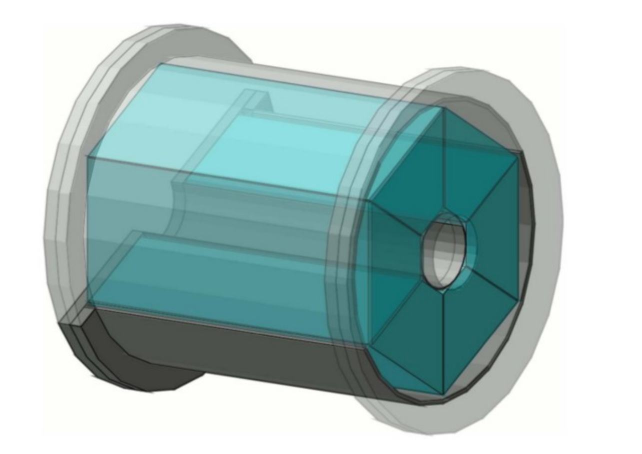

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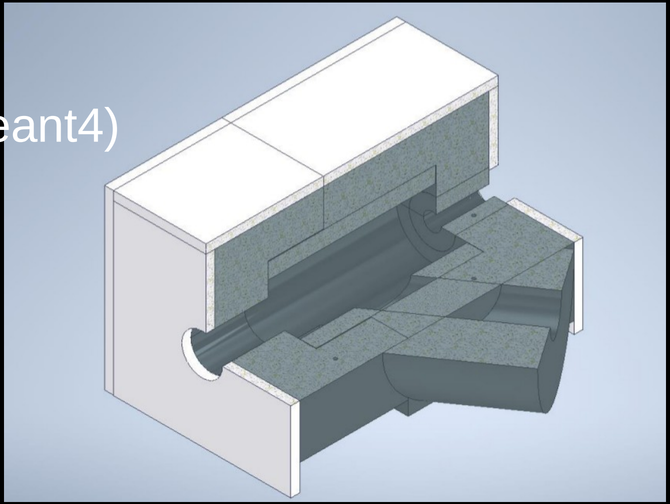
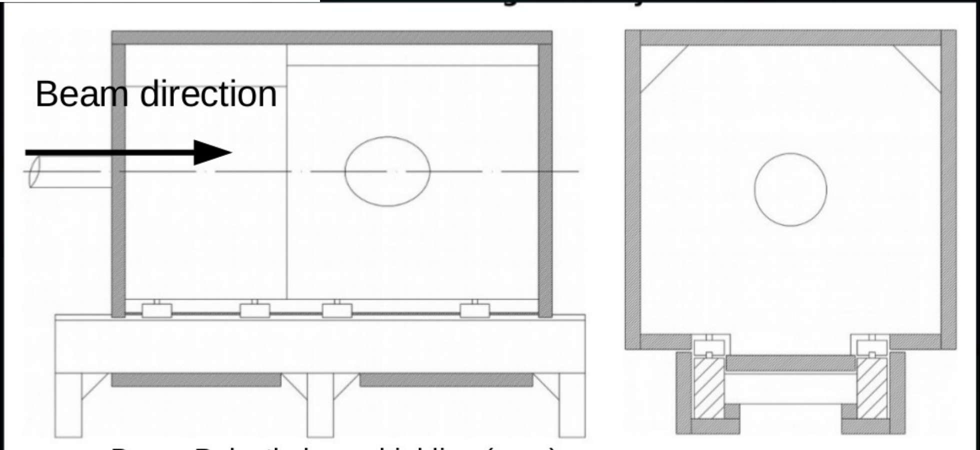
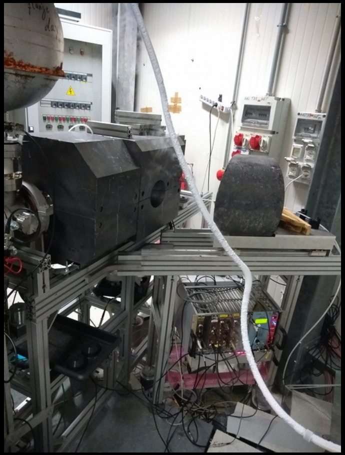


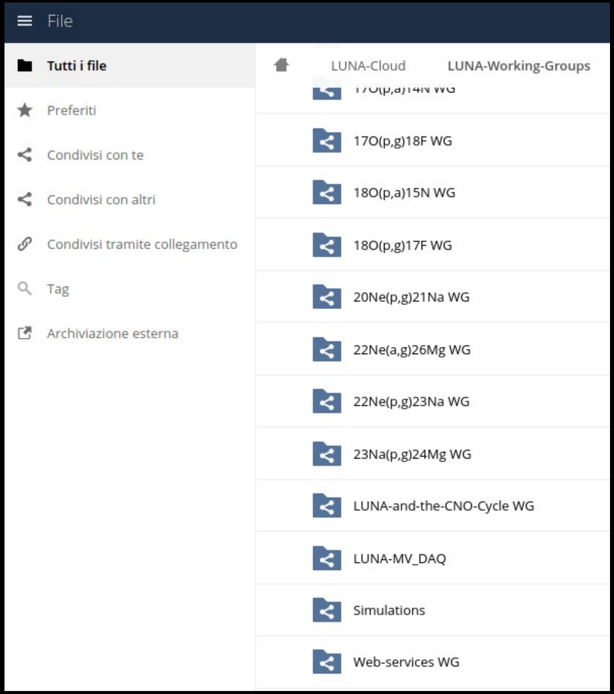


Boron Polyethylene shielding (gray)



SimLuna

- Documentation



SimLuna
A first step toward a unified simulation software for LUNA collaboration

SimLuna is a skeleton application using Geant4 framework. It is a skeleton because it contains only the necessary classes to be "dressed" later in order to achieve a fully functioning software.

Where to find the application

/nfs/luna01/simulations/SimLuna	directory for source files
nfs/luna01/simulations/SimLuna-build	build directory (executable and macros)

Description of the classes

1. The classes are stored in SimLuna directory.
2. There is an inactive and an active module in the application that serve as examples how to add a simple structural (inactive) and a sensitive detector (active) element to the experimental setup. These are called `InactiveModule` and `ActiveModule`. The user must give a name for his/her element instead of `InactiveModule` and `ActiveModule`.
   a) `InactiveModule`, `ActiveModule`: the solids and the logical volumes are created here. The sizes must be defined in these classes. Materials are called using `Materials` class (see later).
   b) `ActiveModuleSD`: implementation of the sensitive detector, fills the hit to be stored
   c) `ActiveModuleHit`: implementation of the hit attached to the appropriate sensitive detector, information (deposited energy, x, y, z, etc.) to be stored in a hit must be defined here
3. The materials for the modules are handled by `Materials` class. Any standard NIST name can be used in the classes `InactiveModule` or `ActiveModule`. In addition, the user can also define his/her own material. This must be done in `Materials` class. An example is given for ^{22}Ne gas. There are some parameters that can be set during run time using a Messenger class called `MaterialsMessenger`. An example how to set the pressure and temperature for ^{22}Ne gas is given.
4. The experimental setup is built in the `DetectorConstruction` class. Instances of active and inactive elements must be called in this class. Also, the sensitive detectors must be attached to the logical volumes here.
5. In order not to confuse the experimental setups of different versions as well as able to store old setups for later checks, the application stores the whole geometry together with the sensitive detector definitions in a Root file. The file name (default: geoSimLuna.root) should be given by the user in a steering macro (see later). These storage is also done in the `DetectorConstruction` class. If the user want to write a geometry file during run time, "write" option must be used (see later).
6. If the user do not want to create his/her own geometry, a stored geometry Root file can be read. This is handled in `DetConstrReader` class. The file name to be read must be given in a steering macro and "read" option must be used when running the application.
7. The geometry storage is performed using Root I/O persistency method. For this purpose a `Classes` header file, `GeoTree` class and an xml file (xml/selection.xml) must be used. Please to not edit these files unless you know what you are doing.
8. A `RunAction` class handles the beginning and the end of the run. At the beginning a timer is started and the histograms are initiated using `AnalysisManager` class.

SimLuna
Changes by versions

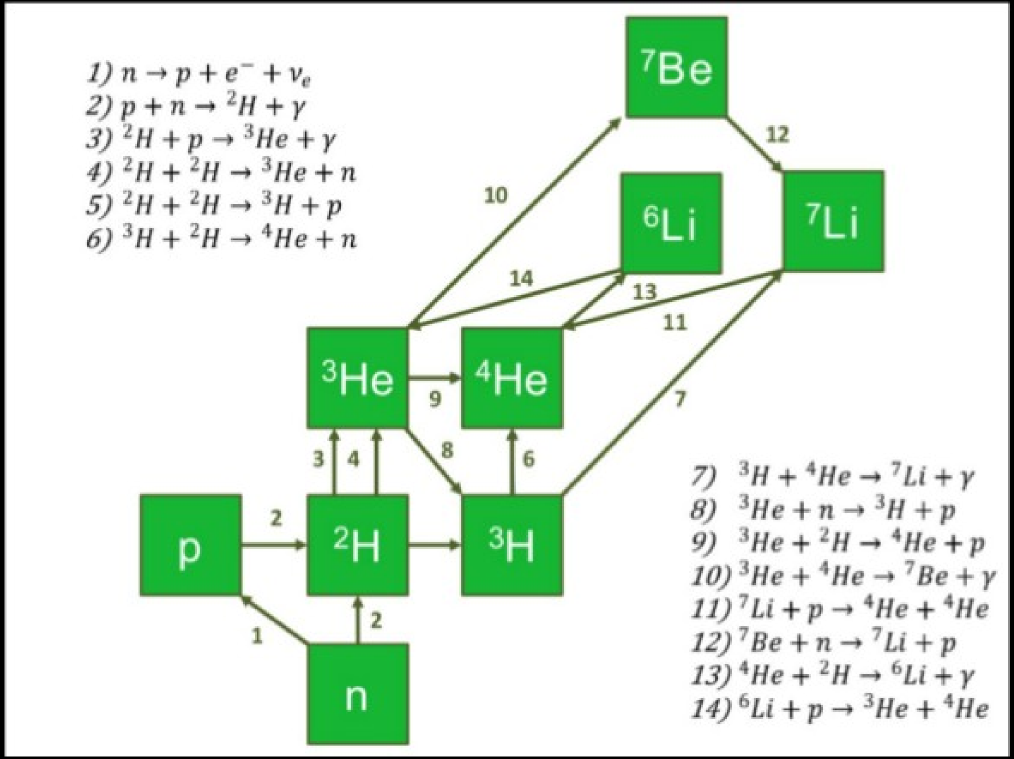
Version 2.0

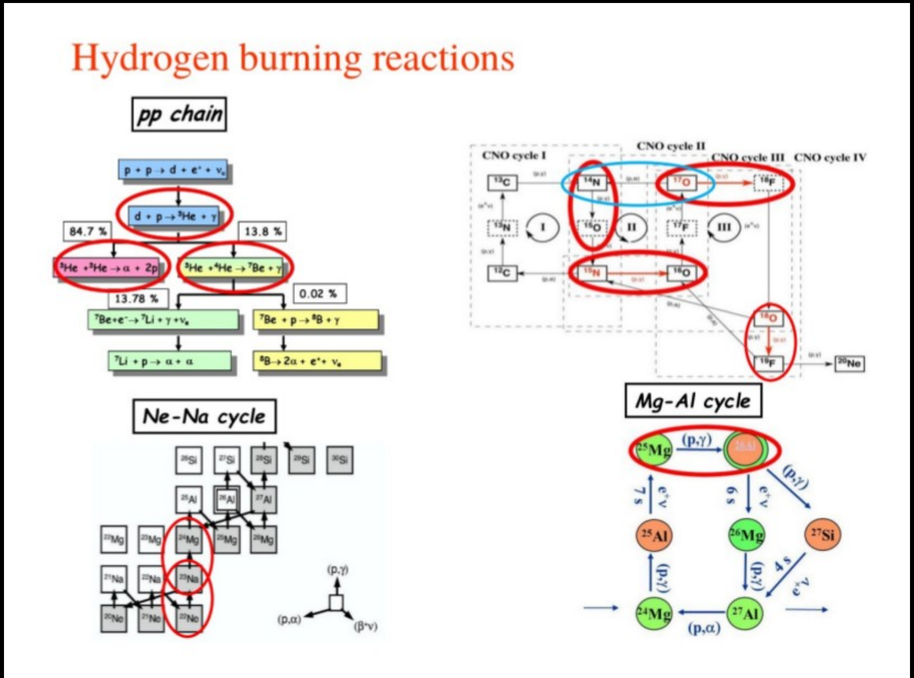
1. New classes `HadronPhysics`, `HadronPhysicsList`, `ParticleCaptureProcess`, `ParticleCaptureDataSet`, `ParticleRadCapture`, `ParticleCaptureXS` have been added in order to be able to simulate reactions. `PhysicsList` has been modified to activate inelastic process and radiative capture process. The inelastic and radiative capture processes use the so-called XS database for the cross sections that is available under G4PARTICLEXS1.1 directory. The files in this directory are text files and can be easily changed. They represent total cross sections. The final states are produced using the `PhotonEvaporation` model. The final state model can be changed in the future if we think it is not appropriate.
2. `SecKinE` histogram changed to `SecGammaKinE` and `SecCosTheta` to `SrcGGCosTheta`.

List of available commands

Analysis
`/analysis/filename`
set the name of the output root file
`/analysis/Gamma1`
set the energy of the first gamma-ray in MeV to be used for gamma-gamma correlation plot
`/analysis/Gamma2`
set the energy of the second gamma-ray in MeV to be used for gamma-gamma correlation plot
`/analysis/CapFragIonA`
set the atomic mass of the fragment ion in capture process for kinematics plot
`/analysis/CapFragIonZ`
set the atomic number of the fragment ion in capture process for kinematics plot
`/analysis/FragIonA1`
set the atomic mass of the first fragment ion in inelastic process for kinematics plot
`/analysis/FragIonZ1`
set the atomic number of the first fragment ion in inelastic process for kinematics plot
`/analysis/FragIonA2`
set the atomic mass of the second fragment ion in inelastic process for kinematics plot
`/analysis/FragIonZ2`
set the atomic number of the second fragment ion in inelastic process for kinematics plot

DetectorConstruction
`/DetConstrReader/filename`
set the name of the input root file for detector setup to be read in, if "read" option is used in the simulation
`/DetectorConstruction/filename`
set the name of the output root file for detector setup to be written, if "write" option is used in the simulation
`/DetectorConstruction/InactModPos`
set the position of the inactive module (example in the simulation)
`/DetectorConstruction/ActModPos`
set the position of the active module (example in the simulation)


1) $n \to p + e^- + \nu_e$
2) $p + n \to {}^2H + \gamma$
3) ${}^2H + p \to {}^3He + \gamma$
4) ${}^2H + {}^2H \to {}^3He + n$
5) ${}^2H + {}^2H \to {}^3H + p$
6) ${}^3H + {}^2H \to {}^4He + n$
7) ${}^3H + {}^4He \to {}^7Li + \gamma$
8) ${}^3He + n \to {}^3H + p$
9) ${}^3He + {}^2H \to {}^4He + p$
10) ${}^3He + {}^4He \to {}^7Be + \gamma$
11) ${}^7Li + p \to {}^4He + {}^4He$
12) ${}^7Be + n \to {}^7Li + p$
13) ${}^4He + {}^2H \to {}^6Li + \gamma$
14) ${}^6Li + p \to {}^3He + {}^4He$
^{7}Be
^{6}Li
^{7}Li
^{3}He
^{4}He
p
^{2}H
^{3}H
n


Hydrogen burning reactions
pp chain
84,7 %
13.8 %
13.78 %
0.02 %
CNO cycle I
CNO cycle II
CNO cycle III
CNO cycle IV
Ne-Na cycle
Mg-Al cycle