Open and New Requirements for HEP experiments

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with contributions from: Ivana Hrivnacova, Sandro Christian Wenzel (ALICE), Vladimir Ivantchenko (CMS), Walter Hopkins, Jana Schaarschmidt (ATLAS), Gloria Corti and Michele Veltri (LHCb), Francois Brieuc, Alvaro Tolosa Delgado, Gerardo Ganis (FCC)

ALICE open requirement UR-59

- **Description:** Improve the inelastic cross sections of anti_deuteron and anti_He3 at low energies (< 1-2 GeV/c)
- **Motivation:** the corresponding values for the inelastic interaction c.s. were published recently in a series of papers [1-3] (see the references on the backup slides)
- In all these cases, an average atomic number <A> of ALICE detector material crossed by antinuclei was evaluated by weighting the materials with their densities times path length; the Geant4 cross sections were evaluated for non-integer values of <A> using the cross sections from the nearest available element and scaled to <A> with an equation (2) of Ref. [2].
- Indeed, the results show some deviations from Geant4 parameterisations here and there, which can be fine tuned to reproduce the ALICE results perfectly.
- **Requirement:** follow up on this update and tune the Geant4 antinuclei inelastic interaction c.s. to these newly available data from ALICE (and establish a contact to Geant4 team).

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ALICE closed requirement: UR-73

- **Description:** Ability to define thresholds in energy
- **Motivation**: The detectors cuts & thresholds in the ALICE framework are defined in energy per tracking medium (= material in the context of Geant4)
  - In total: 363 materials, 333 user limits
  - These are first converted into the ranges, then set to the regions defined according to the materials and then converted by Geant4 into energy
  - The final energy threshold does not match exactly the initial value due to the approximations
- **Requirement**:
  - Either have a method per region & material to set the cuts in energy
  - Or have a possibility to predefine G4ProductionCutsTable with the energy thresholds that would not be then recomputed
  - Or, if none of the above cannot be done (?), *provide a fast EnergyToRange converter* that could replace the users computations

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ALICE requirements addressed in Geant4 11.2

- **Geant4: v11.2**
  - New function SetEnergyCutVector(...) and one more that allow to set productions cuts in energy and so to avoid double conversion energy - ranges – energy, added in the G4ProductionCutsTable
- **Geant4 VMC (Virtual Monte Carlo): v6.6.p2**
  - A new method G4RangeManager::DefineRegions2() is implemented in Geant4 VMC version v6.6.p2 deployed by ALICE
  - The inconsistencies due to double conversion are removed
- However update to Geant4 11.2 brought a new issue
  - Not taking into account a special Multiple Scattering model (tuned for ALICE) on the top of FTFP_BERT_EMV physics list (caused by new combined TransportationWithMsc processes included by default with EMV option)
  - The issue caused delayed deployment of Geant4 11.2 until the problem was understood and fixed in August '24
- **NO new requirements**

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CMS requirements

- CMS strategy for FullSim is to use the most recent public release of Geant4
- It is shown that Geant4 physics between versions 10.6 and 11.2 is nearly the same
- A lot of new technical features are introduced by the Geant4 team into each new version of Geant4 essential for the CMS Phase-2 simulation developments
- Geant4 versions in CMSSW:
  - Run2 – 10.4.2
  - Run3 2022-2023 – 10.7.2
  - Run3 2024 – 11.1.2
  - Run3 2024 HI – 11.2.2
  - The current Phase-2 -11.2.2

- **Open requirement:** design parallel initialisations (could not find it in Jira?)

- **No new requirements**

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FCC status and needs

- The FCC project is still in an **early stage**
  - → most needs are yet to be identified!
- First geometry implementations for three FCC-ee detector concepts (CLD, IDEA, ALLEGRO) are ready
  - started to use those models in physics studies (e.g. beam induced background occupancy)
- Tuning of the Geant4 parameters is now being addressed
- From the current studies (for the Feasibility Study Report) the following **needs** can be anticipated:
  - Very large statistics ($5*10^{12}$ Z bosons i.e. LEP*10^5) + very clean environment
    - → enables ultra-precise measurements
    - May reveal sensitivity to tiny effects neglected e.g. in hadron collisions
    - Will need simulation to be fast but without jeopardising accuracy

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FCC status and needs

- Most detectors will feature very high granularity:
  - Interest in having 64 bits for VolumeID (DD4hep "cellID" is 64 bits)
- Some will use new or uncommon shapes (c.f. recent bug fix in twisted tubes navigation)
- Modelling of high intensity beam effects
  - E.g. synchrotron radiation interaction with beampipe done with Geant4 (BDSim), needed a more precise treatment of X-ray reflection (now included in Geant4 11.2)
- Possibility to fully rely on Geant4 Photo Absorption Ionization (PAI) model for gaseous detector cluster counting techniques
- FCC-hh (longer term) at ~ 100 TeV: particles with unprecedentedly high energy
  - E.g. fast multi-TeV calorimeter shower simulation

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FCC status and needs

- **General important requests:**
  - **Include** relevant developments done internally by experiments in the Geant4 releases and advertise them, with long term visibility
    - Otherwise those developments are lost for the community…
  - **Document Geant4 configurations** used by experiments so that the future projects can benefit from accumulated knowledge

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ATLAS open requirement: UR-72

- **Description:** Centralised repository for BSM particles
- **Motivation:** Many experiments need to simulate BSM particles. Individual experiments have implemented extensions to Geant4 to add support for additional particles and processes.
- **Requirement: Create a centralised repository for such modules that all experiments can benefit from/contribute to**
    - E.g. modules for R-hadrons, monopoles, quirks, etc.
    - Initial chat with Alberto in May:
        - As first stage, we could collect links - e.g. in our Geant4 web page - to GitHub code repositories of the LHC experiments where examples of BSM treatments, at the level of detector simulations, are shown.
        - As a second, eventual stage, more ambitious, we could transform some of these "code snippets" as Geant4 examples (e.g. under geant4/examples/extended/exoticphysics/), which do not depend from any software framework, and are kept updated with Geant4 by the Collaboration (and not by the experiments).

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ATLAS open requirements

- **Description:** Improve treatment of Quasi-stable particle Simulation: **UR-89**
- **Motivation:** Some MC Event Generators treat the oscillation of neutral B mesons as a 1 -> 1 transformation, e.g. from B0 to anti_B0, or vice versa, happening in the same space position where the meson then decays.
  - This implies that the "oscillation vertex" coincides with the "decay vertex", and this creates problems to Geant4.
- **Requirement:**
  - Improved robustness of Geant4 when using pre-defined decay chains from Generators.
  - Establish conventions on consistency of decay models between G4 and Generators where there are overlaps

- **Description: Introduce** UI commands to set the FTF parameters
  - Could not find it in the list
  - Maybe already addressed?

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ATLAS new requirements

- **Description:** Guarantee physics stability through Geant4 versions (a.k.a The importance of having a stable physics)
- **Motivation:**
  - In ATLAS changes in physics modeling within the Monte Carlo (MC) simulations require updated recommendations for physics objects
  - This is a resource-intensive process, mainly in terms of person-power but also computing power, and is typically undertaken only once or twice per LHC run.
  - Improvements in physics modeling can only be incorporated into production releases when new physics object recommendations are scheduled.
  - Technical optimizations that enhance performance can be added to production releases between data-taking years in an LHC run, provided they do not affect the physics modeling.
  - These requirements slow down the adoption of new Geant4 versions (if the physics is changed)

- **New requirement:** have the possibility to disentangle updates to the physics to updates to the rest of Geant4. In other words have the possibility to adopt new version of Geant4 keeping the physics stable

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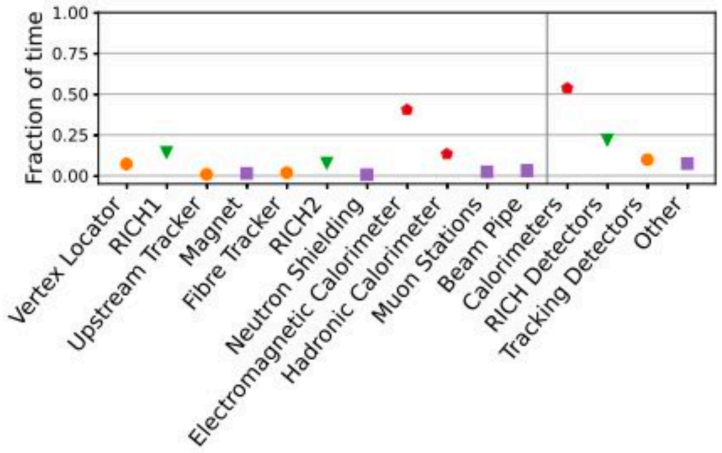
ATLAS new requirements

- **Description:** Switch-off energy loss fluctuation in Geant4 depending on particle type/detector region
- **Motivation:**
  - In Geant4 energy loss process calculates continuous and discrete losses per step
    - Both are stochastic processes, mean value of continuous loss can be calculated from (restricted) stopping power.
    - Statistical fluctuation around this mean from Urban/PAI models in Geant4
  - Sampling these models adds (small) compute time per step, but fluctuation can often be ignored if number of steps is large in important volumes
  - Statistical variation in energy loss over steps dominates per-step fluctuation
- When switching this process OFF ATLAS observed Changes on Egamma energy scale larger than calibration systematic and a higher catastrophic energy loss, with a 1% mismatch for muons with pT>500GeV
- **Requirement**: add the possibility to enable the switch-off option depending on particle types / detector regions.

LHCb open requirements: UR-92

- **Description:** Add a way to turn on/off Cherenkov effect per logical volume
- **Motivation:** In **LHCb** the **computational resources** for the full simulation based on
  Geant4 are dominated by the calorimeters and the two Ring Imaging Cherenkov (RICH) detectors
  - Some **simple optimization strategies** of the optical processes have been
    adopted in order to reduce the number of optical photons to be propagated:
  - **Requirement:** introduce the possibility to switch off of the Cherenkov effect per logical volume with a flag



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LHCb open requirements: UR-93

- **Description:** Add a way to handle particles unknown to Geant4 modeled on G4GenericIon
- **Motivation:** Exotic particles, excited B and ions, often produced at generator level, are not known to Geant4
  - The standard Geant4 approach to create a unique static object derived from the `G4ParticleDefinition` class for each new particle doesn't scale
  - **A first attempt to create dynamically the "unknown" particles failed** → Must be done at initialization
    - The adopted solution is to implement at initialization all the particles known to the LHCb ParticlePropertyService (not creating however a specific class for each particle, just an appropriate instance of `G4ParticleDefinition`)
  - In the case of **unknown ions**, an abstract prototype exists, the `G4GenericIon` which is created by default, and has all the processes already attached
    - The new, unknown ion can therefore be dynamically created on top of `G4GenericIon` using the `GetIon` method of the `G4IonTable` class
- **Requirement:** A similar approach with a "`G4GenericParticle`" prototype created by default at initialization time, could be a solution to this problem with the advantage of reducing the size of the `G4ParticleTable`

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LHCb: status and requests

- LHCb has been working of R&D activity related to Geant4, in particular
  - Integrated the **ML CaloChallenge**-like provided by Geant4 in Gaussino. Reproduced the Geant4 example in Gaussino and now performing an advanced validation phase for its use with Gauss(-on-Gsino) in LHCb. Very fruitful collaboration with the Geant4 FastMC group on this, that it is planned to continue.
  - Integrated AdEPT in Gaussino and are now carrying out early test with the LHCb specific Gauss simulation (report in the AdEPT R&D talk)
  - Exploring other Geant4 developments, e.g. the use of the G4GammaGeneralProcess with the EM_opt2 physics list maintained by G4 for LHCb
  - **New Requirement:** Planning to start the process to move to Geant4 11 sometimes next year. Current production version is Geant4 7.3 and it may be needed to forward port to gcc13
    - could this be supported (patches for gcc13 compilation are available and can be provided to G4)?
  - **New Requirement:** Request for tutorial and examples on the new MT tasking mechanisms in Geant4 11, and in case of new developments in this to have discussions at the design phase to minimise the overhead to integrate it in the experiment framework.

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Common highlights

- Upstream to Geant4, experiments specific developments:
  - BSM physics centralised repository
- General concern about lack of support/documentation on the new Task based parallelism
- Improve decay modules/interface to generators
- Fast simulation support
  - Intensive R&Ds ongoing in each experiment
  - Framework support and generic techniques such as biasing etc.
  - Fast simulation developments must be relevant to real detector issues and have direct integration in the experiment's framework.
- There is a vivid interest in optimizing CPU and memory usage in Geant4
- There is widespread interest in heterogeneous hardware across all experimental collaborations.
  - Improved support for running on GPUs.
  - Developments are ongoing to integrate Celeritas/AdePT and G4HEPEM into the experiments

Sincere thanks to the Geant4 experts for their invaluable collaboration and continuous support !

Thanks for your attention!

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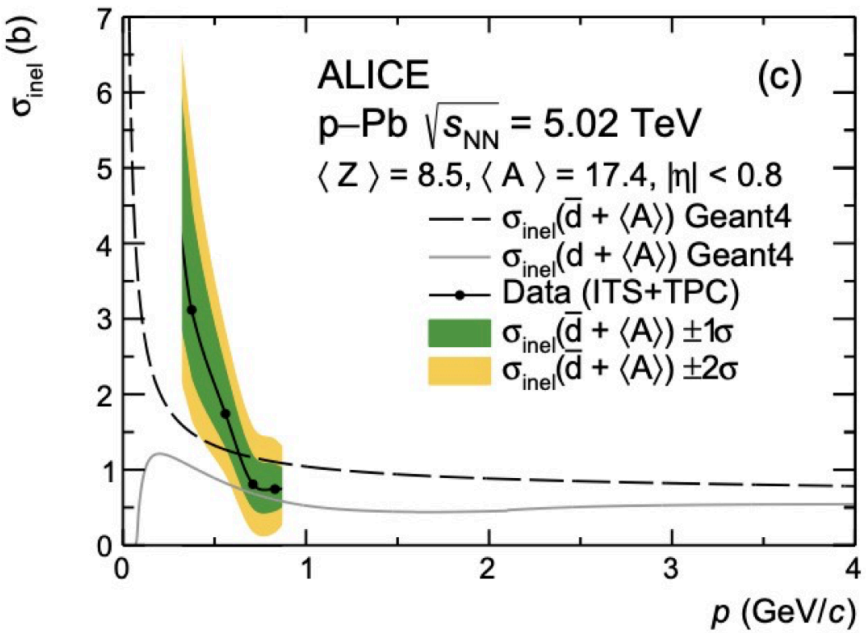
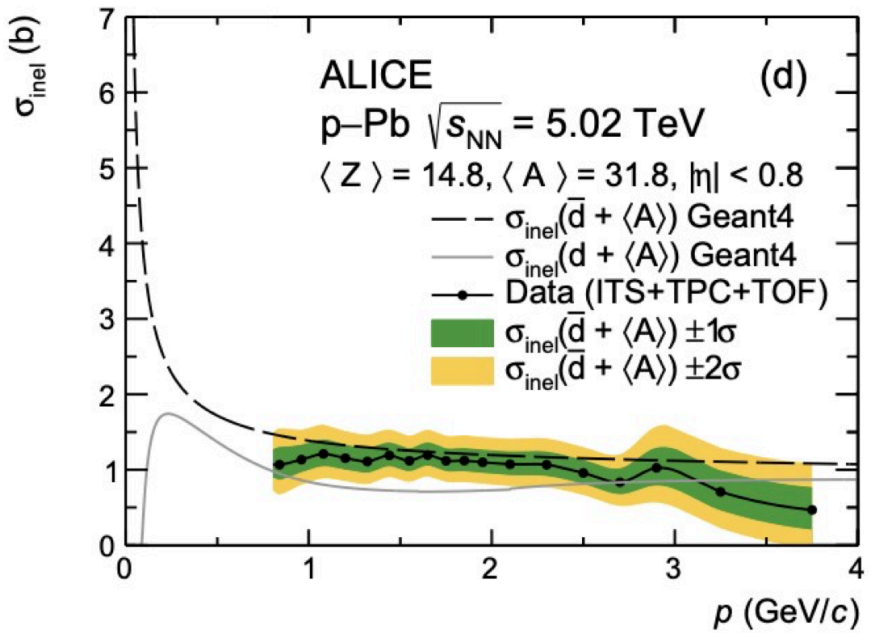
Backup slides

ALICE requirement UR-59

- [1] Antideuteron inelastic c.s. (relevant results: Fig. 3 (c) and (d))
- https://inspirehep.net/literature/1797442
- HEP data (tables 13-16): https://www.hepdata.net/record/ins1797442





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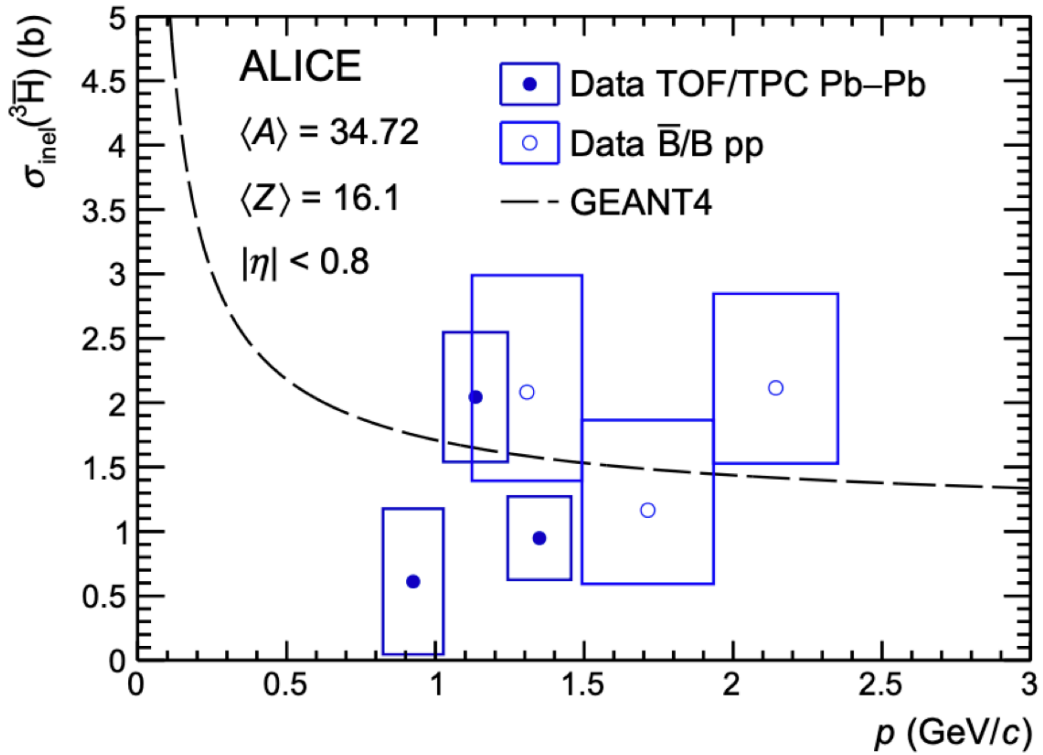
ALICE requirement UR-59

- [2] Antitriton inelastic c.s. (Fig. 2 left)
- https://inspirehep.net/literature/2675130
- HEP data (tables 9 and 10): https://www.hepdata.net/record/ins2675130



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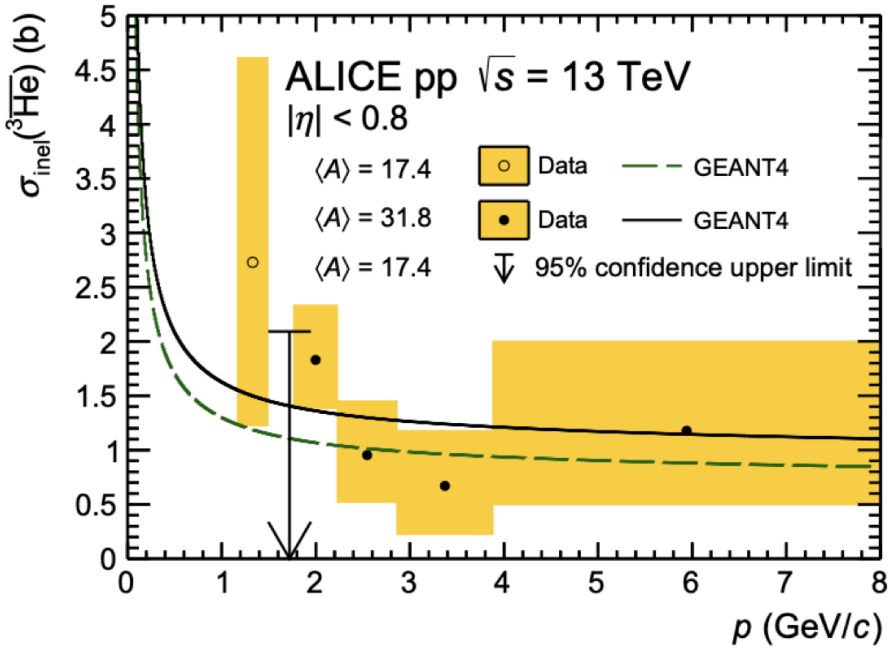
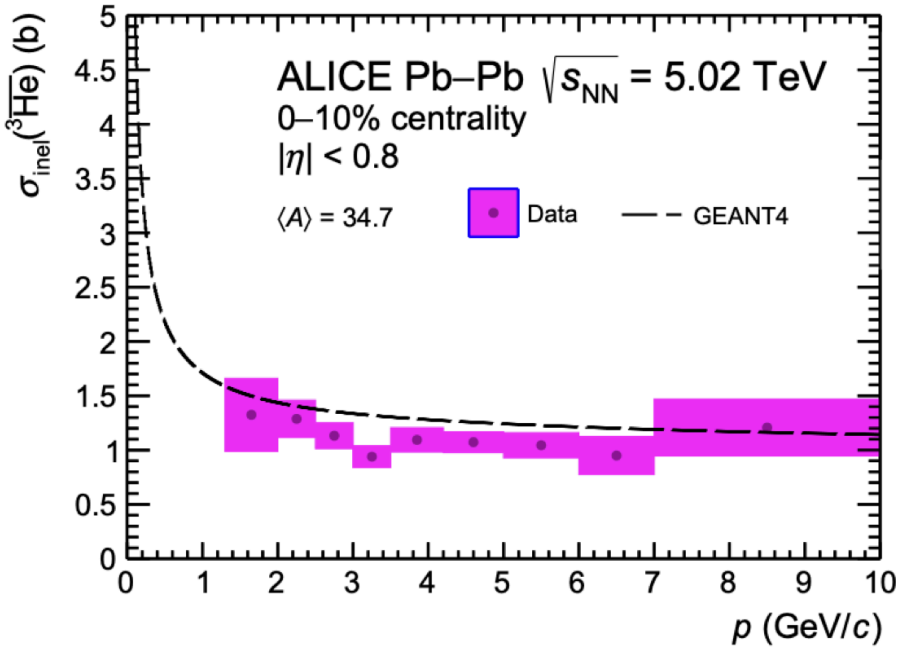
ALICE requirement UR-59

- [3] Antihelium-3 inelastic c.s. (Fig. 2)
- https://inspirehep.net/literature/2026264
- HEP data (tables 9-11): https://www.hepdata.net/record/ins2026264





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Requirements lacking people who could work on them

Issue	Labels	Summary
UR-28	4001	Anti-proton production from proton beam
UR-32	4005	Neutron production in muon showers at the %-level
UR-49	5005	Neutron self-shielding effect
UR-62	5301	Model for positroniium creation and annihilation
UR-63	5302	To have an extended example to retrieve directly from the simulation Auger electron energy and associated atomic transition
UR-65	5304	Beta-delayed Neutrons : develop understanding of highly excited level densities in nucleus and model neutron decay from this region
UR-66	5305	Fix overproduction of n and p near endpoints of reactions at 4.5 GeV
UR-69	5502	Ability to turn off intranuclear scattering
UR-71	5504	Excess ratio of pi-/pi+ in p W reaction with Bertini
UR-80	5709	Isotope production from protons using IAEA medical cross-section
UR-82	5711	Geant4-DNA physics processes for positrons
UR-85	5714	Making MENATE_R package available as an alternative model
UR-87	5716	Include (currently customised for SuperCDMS) databases for PhotonEvaporation and RadioactiveDecay in the official releases
UR-94		Couple Bearden energy lines with ANSTO fluorescence data libraries

ATLAS requirements: UR-75

Description:

- **Radiation Modelling:** Geant4 10.6 and later versions showed more total ionizing dose (TID) and neutron fluence compared to Geant4 10.1.
  - There is a high discrepancy (~30%) between 10.1 and 10.6 (or 10.7 or 11.0) in terms of neutron spectra in HP physics lists.
    - G4 was already higher in neutron fluence compared to FLUKA for 10.1 and now is even higher
    - Major suspect: the caching code for Particle in the HP physics lists
- **Look at the HP physics lists (in particular at the caching code)**
  - Update: The recent investigation on the hadronic physics list by Lorenzo might have an impact, study is ongoing
- **STATUS**: closed

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ATLAS requirements

► 1st row: G4.10.6 over G4.10.1 (Run-2) ► 2nd row: G4.10.6 over G4.10.6 with old BERT (Run-3) – all with PhotEvap to avoid TID bug