Calling Pythia8 to handle an interaction during a Geant4 simulation

27th Geant4 Collaboration Meeting

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1. Background & Context

- LHC style experiments *typically* have clear separation between event generation and detector simulation
  - This is less true for other HEP applications
  - Signal process often happens in the middle of the simulation
- Context for our work is Light Dark Matter eXperiment (LDMX) and KAW-LDM project
- Two goals
  - Flexible signal simulation for LDMX using Pythia8 in Geant4
  - Making what we learn useful outside of our particular use-case
- Two reference applications for studying this
  - Carried out in collaboration with colleagues from the Lund Pythia group

1.1. KAW-LDM

- Project aiming at lasting impact on wider Swedish DM landscape
  - LDMX participation
  - DM Simulation aspects
  - Statistical inference & global data interpretation
  - Detector material evaluation for direct detection
- Use LDMX challenges and results to drive research and collaboration between theory and experiment

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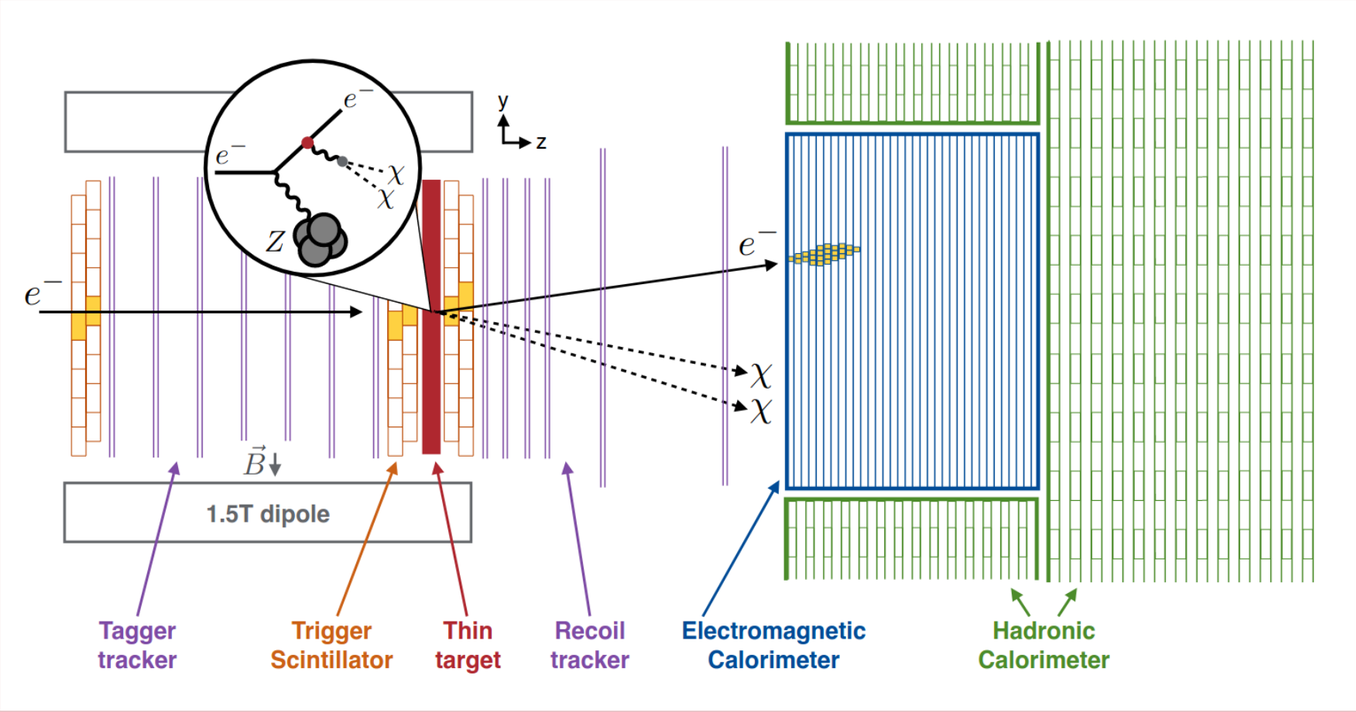
1.2. LDMX



From LDMX Current status/prospects, https://arxiv.org/abs/2203.08192, Fig 1

2. Pythia8 as an primary generator

- Wanted a simple Geant4 component but with full-featured Pythia events
  - Picked a Pythia8-based primary generator action combined with a version of **J. Yarba**'s Py8Decayer example
  - Can also take decays directly from Pythia event
- In principle not different from pre-generating events and reading from disk
  - Similar tools are used by some experiments already
  - Offers a different UX
  - Allowed us to write a large portion of the interface code we need for more complicated projects and discovering pitfalls
- Unit testing was crucial
- Currently relying on system installation of Pythia8, could be relevant to write CMake code to (*optionally*) build

3. Hadronic interactions: Cosmic rays

- Using Pythia *applications* as models for hadronic interactions
- From discussions with Lund Pythia developers where they saw interest in adding Geant4 features to a Pythia application
  - Recent work by **T.Sjöstrand** and **M. Utheim**, including inelastic hadron-nucleus interaction at arbitrary energies for simplified nuclear matter
  - Each interaction is treated as a series of Pythia collisions between hadrons
  - For the physics: See T. Sjöstrand & M. Utheim Eur. Phys. J. C 82, 21 (2022)
- Doesn’t rely on any hard processes in Pythia
  - Only Soft QCD and Low-energy QCD processes
  - Allows for using a single Pythia object for each sub-collision and every event
    - Beam species and energy can be changed without setting up a fresh Pythia object
- However, embedding a full application is more complicated than typical event generation
  - Want to establish a corresponding interface to wrap this
- Extended/Hadr02 for CRMC was extremely useful here

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4. Flexible signal simulation

- Hard process simulation for experiments like LDMX
- LDMX has a simulation/reconstruction framework including Geant4 simulation with a model for dark bremmstrahlung in target (LDMX-sw)
  - Signal simulation relies on library of pre-generated events from MadGraph for various electron momenta
  - Works for a given model, but changing models is non-trivial and not feasible for people outside of the LDMX software group
  - On-going work in the KAW-LDM project by **L. Gellersen**, **T. Gray**, **R. Pasechnik**, and **R. Catena** to use Pythia8 to explore further DM models
- Instead, use exact kinematics of the event
  - Requires a Pythia object set up for specific beam type and kinematics
  - Strategy for handling creation and lifetime of such objects will be a crucial challenge
  - As will interactions with multiple threads