Detector Software Strategy and Plans

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FUTURE CIRCULAR COLLIDER

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Content

- General overview
- Where do we stand?
- Short term plans
- Going further

Main focus on FCC-ee here but generic software tools can be initial state **flavor agnostic** to a large extent

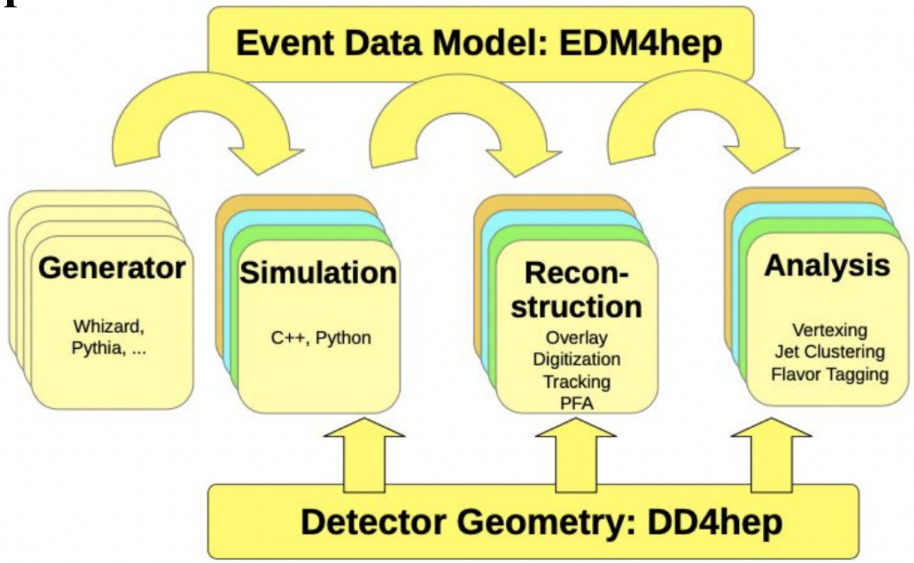
Motivations

Why a joint Detector R&D/Software session?

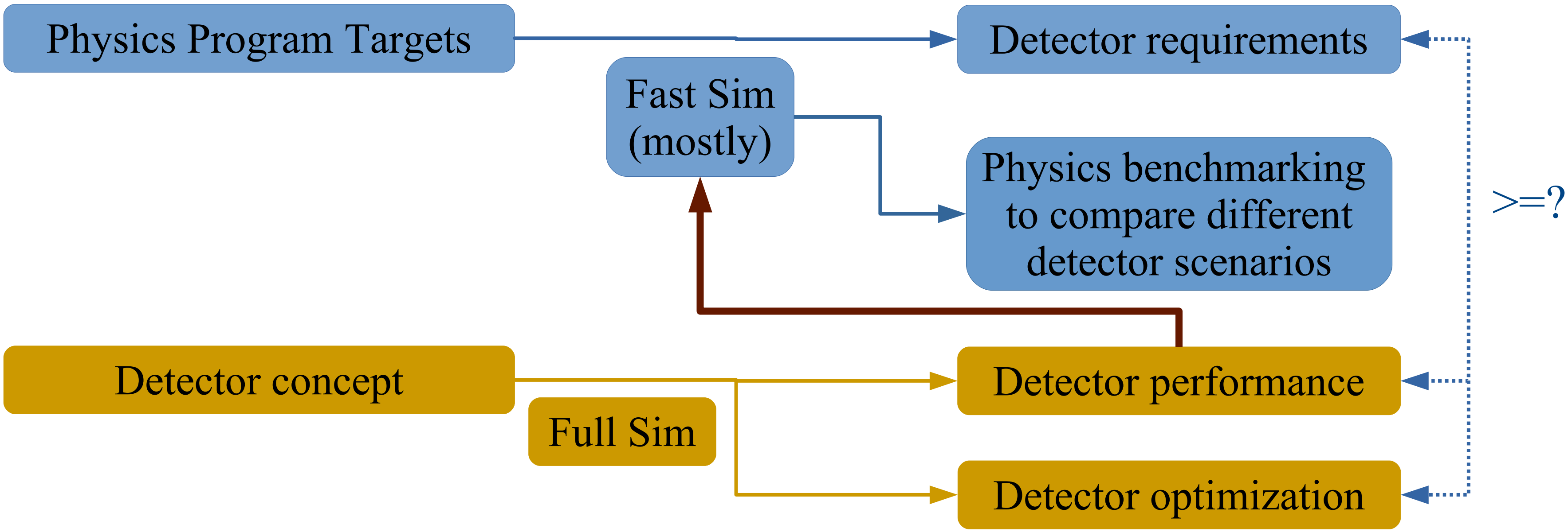
- One can not prototype every sub-detector option → software studies (meaning **full sim** here) are a must for **sub-detector optimization**
- Great progress recently made in physics case studies with parametrized simulation (Delphes), it is now time to complement with full sim
  - Precise **determination**/validation of the **parameters used in fast sim**
- We have to show that **complete detectors,** meeting **requirements,** can be **designed**
  - Before the final detector is built, full sim is the only place where **all sub-detectors live together and interact with each other** in a realistic way

General Overview

- Detector R&D and optimization campaigns **span over decades**
  - Need a **stable** and continuously **maintained** software framework
- Future collider studies performed by **small teams** (compared to operating detectors)
  - Exploiting **synergies** is a must
- The community agreed on using a common software framework for **all future collider studies**: **Key4hep** (more details in Gerardo's talk)
  - Complete set of tools: generation, simulation, reconstruction, analysis
    - State of the art HEP libraries availability: **Spack**
      - Avoid re-inventing the wheel
  - Common data format: **EDM4hep** (PODIO)
    - Easy sharing
  - Detector description with **DD4hep**
  - **Gaudi** orchestration



Detector Feasibility Study

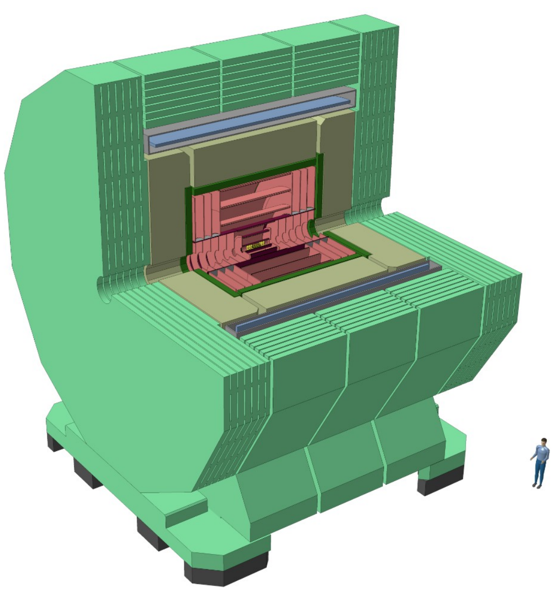


- Full Sim does not easily allow to sweep detector free parameters
  - Can evaluate a few benchmarks and extract trends from them
- Comparing detector scenarios based on a few performance metrics is not enough
  - How do they combine together?
  - May want to define some key analyses (families) to assess detector scenarios potential
  - Unrealistic to perform all the Full Sim key analyses for each detector scenario
  - Way easier to plug detector parameters in Delphes to evaluate its physics performance
- The optimization phase will be long → FCC physics case analyses should survive the analyzers (i.e. keep them maintained and easy to run)
  - FCCAnalyses

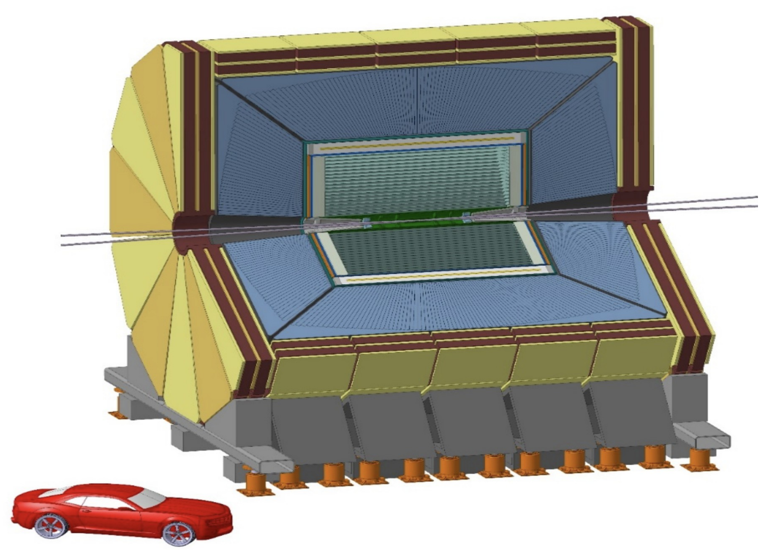
FCC-ee Detector Concepts

- Two concepts proposed for the FCC-ee CDR: **CLD, IDEA**
- More detectors needed if we have more than 2 IPs
  - New concept based on **High Granularity Noble Liquid calorimeter** under development
- Many different sub-detector technologies on the table!
- Ultimate goal pursued: **full inter-operability of sub-detectors** (eased by DD4Hep plug-and-play approach) and **reconstruction algorithms** (dataformat, more challenging)

CLD



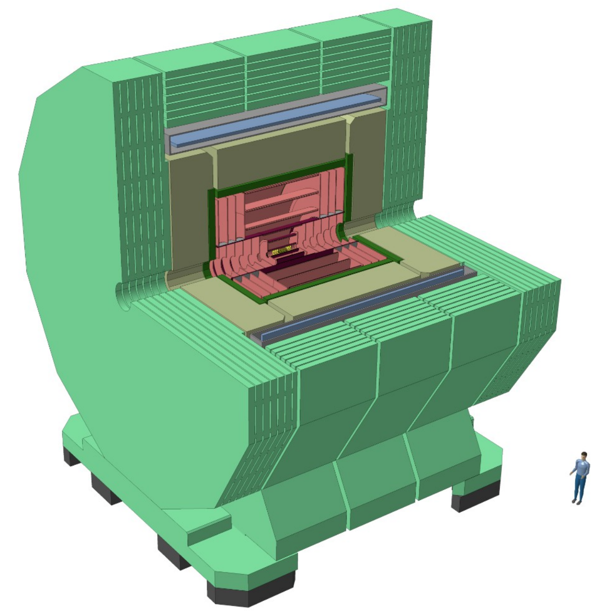
IDEA

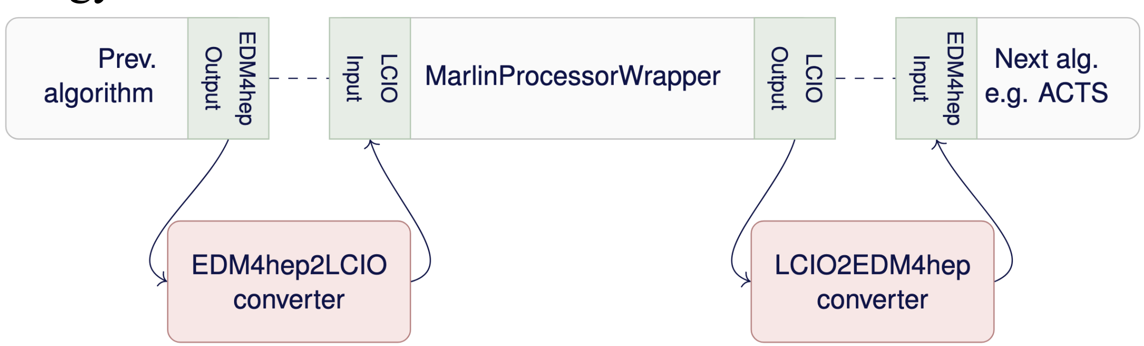


Noble Liquid Based

CLD Full Sim Status

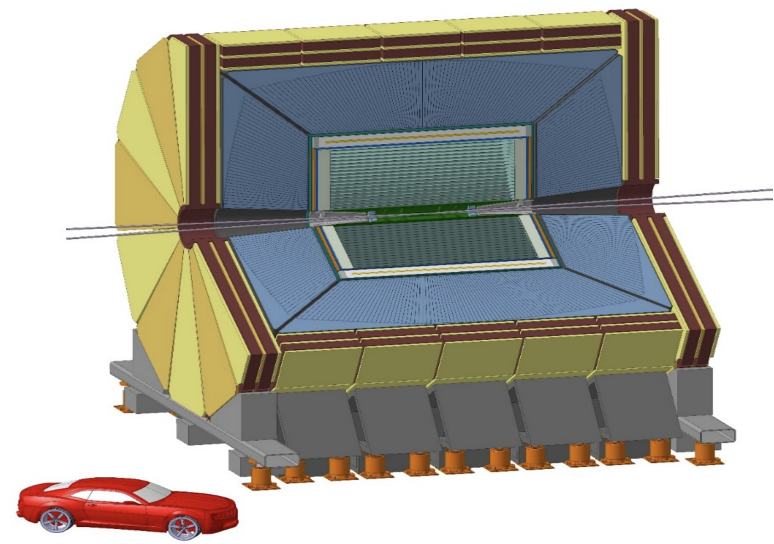
- **All CLD sub-detectors implemented in DD4hep**
  - Several configurations envisaged
- Simulation based on ddsim
- **Reconstruction well advanced**
  - Background overlay, conformalTracking, ParticleFlow (PandoraPFA), vertexing and flavor tagging (LCFIplus)
    - Inherited from ILD/CLICdet
  - **LCIO data format**
- Can be **integrated in EDM4hep Gaudi based workflows**
  - With some data format transition gymnastic
  - More validation needed





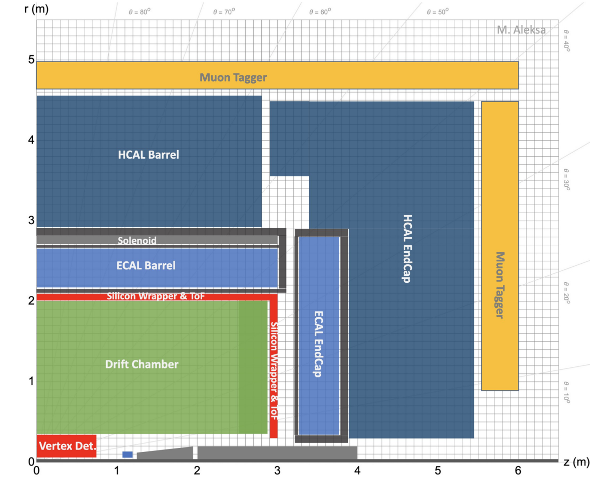
IDEA Full Sim Status

- **'Standalone'** (plain **Geant4**) detector simulation
  - Detailed drift chamber and dual readout (DR) calorimeter
  - Simpler description of the vertex detector and pre-shower
  - Muon detector (µRwell) in progress
- Full reconstruction not available yet
  - Tracker hits and tracks + calorimeter hits are there
  - Working on Particle Flow implementation
- **Ongoing effort towards Key4hep integration**
  - Porting detector description to DD4hep: DR calorimeter done, drift chamber ongoing
  - Detailed implementation of the vertex detector in DD4hep ongoing
    - More details later in this session: Armin's talk
  - Possibility to output hits and tracks in EDM4hep under validation
- Upcoming development: Crystal ECAL in DD4hep (study the option DR + crystals)



Noble Liquid Based Full Sim Status

- Detector concept in its infancy
- Development started immediately with Key4hep in mind
- DD4hep ECAL barrel implementation validated
- HCAL and ECAL end-cap implementation under validation
- Drift chamber detector from IDEA simplified version
    - Very easy from the 'plug-and-play' approach
- Clustering algorithms available in Key4hep (sliding window, topological clustering, Clue)
- Further developments
    - ECAL/HCAL interface
    - Choice of magnet position based on realistic field maps
        - Tools implemented, impact on tracking to be assessed
    - Particle Flow
    - …

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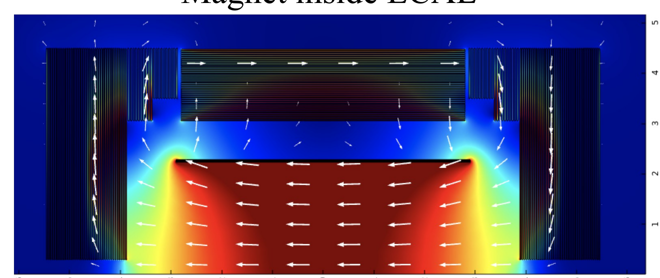
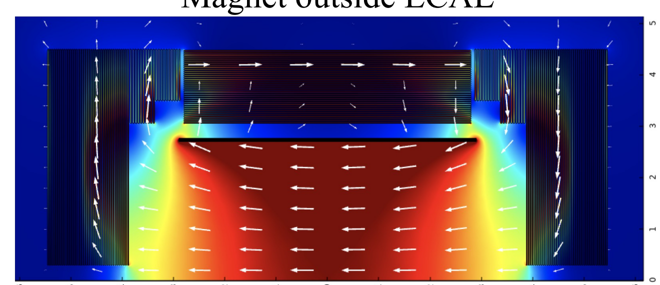
Magnet inside ECAL



Magnet outside ECAL

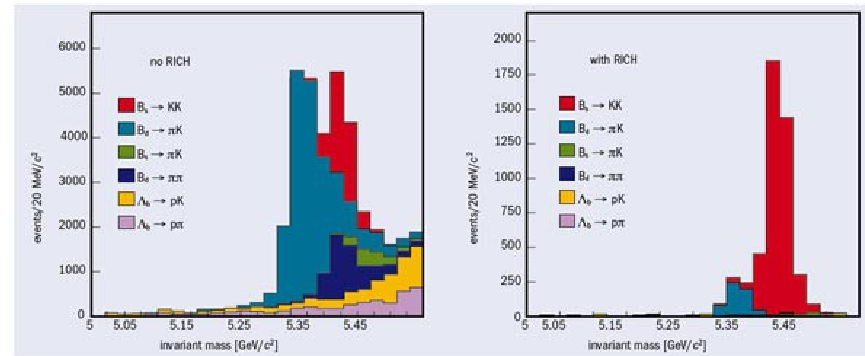


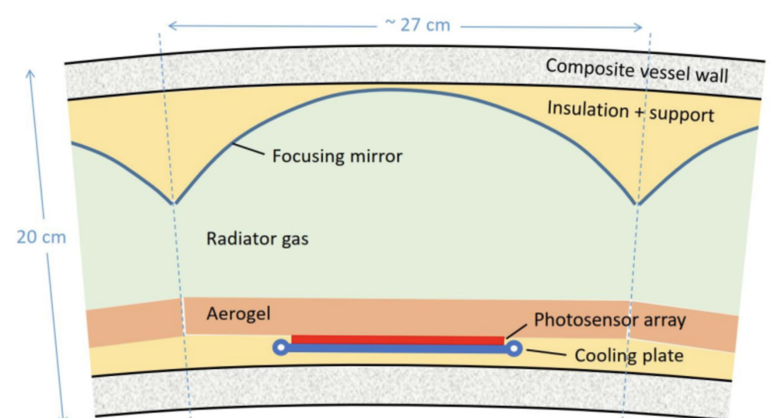
N. Deelen

PID Detectors

- Detector **layouts are not frozen**!
  - Exploring further sub-detector technologies
- Particle ID greatly enhances **flavor physics reach**
- **Particle ID detectors** can complement/replace dE/dx or dN/dx
  - Technology more mature then at the LEP time (DELPHI)
    - LHCb RICH
- **Accurate** and **comprehensive** estimation of what it brings needs full sim
  - Photon yield/collection, additional material budget
  - Quite difficult to implement
- **A**rray of **R**ICH **C**ells (ARC) being implemented in DD4hep
  - More details in the next talk by Martin Tat

$B_s \rightarrow KK$, LHCb simulation

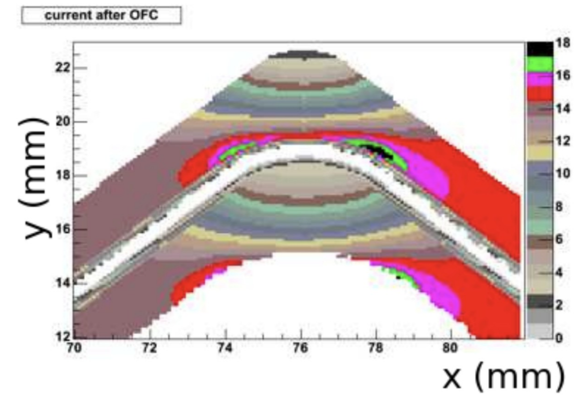


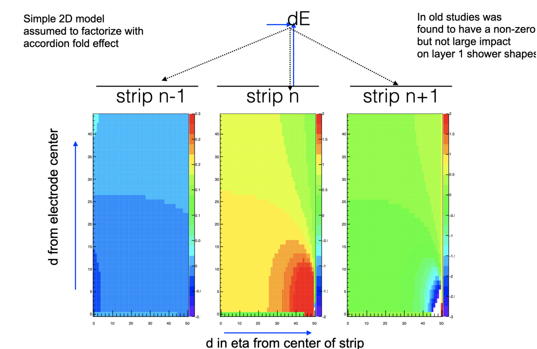


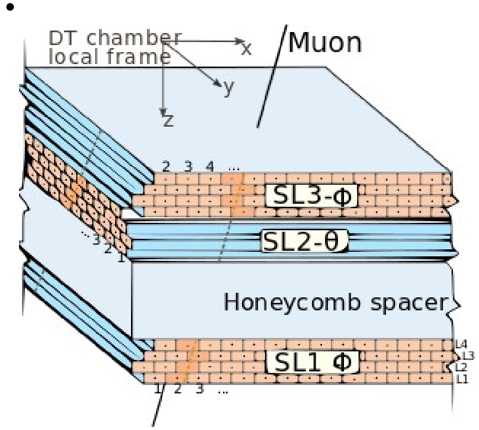
ARC detector (one cell)

Digitization

- More work needed on **digitization**
  - Calorimeters: scaling Geant4 energy deposits to match initial particle energy so far (sampling fraction)
- Robust estimation of detector performance require these tools
  - Calorimeters front-end electronics **dynamic range**
    - FCC-hh: particles with 10's of TeV
    - Should also be considered for FCC-ee
      - Narrower energy range but smaller 'minimal' energy (high granularity, low noise)
  - Drift chambers: how to go from G4 energy deposit to the wire signal (in DD4HEP)?
  - **Beam background overlayed** at reconstruction step or **before digitization?**
    - HL-LHC CMS Drift Tubes
  - Charge collection effects, energy sharing, field non uniformities, cross-talk
- Two talks dedicated to digitization modeling in this session
  - CALICE lessons learned in Vincent Boudry's talk
  - Modeling signal digitization for trackers in Riccardo Farinelli's talk





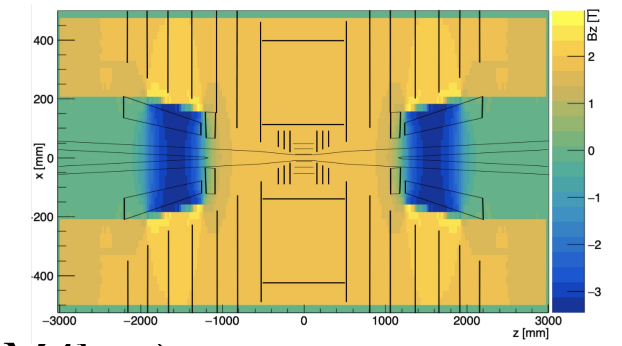


Going further

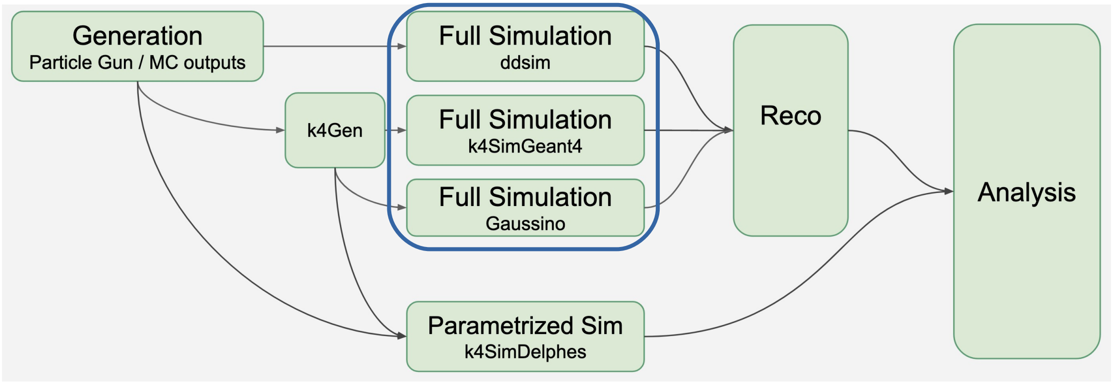
How could we further improve?

- MDI
  - Improve beam background overlay workflow
  - Produce field maps with the interplay between beam magnets and detector magnet fields (also has non-uniformities)
    - Impact on the Tracking performance

A. Ciarma



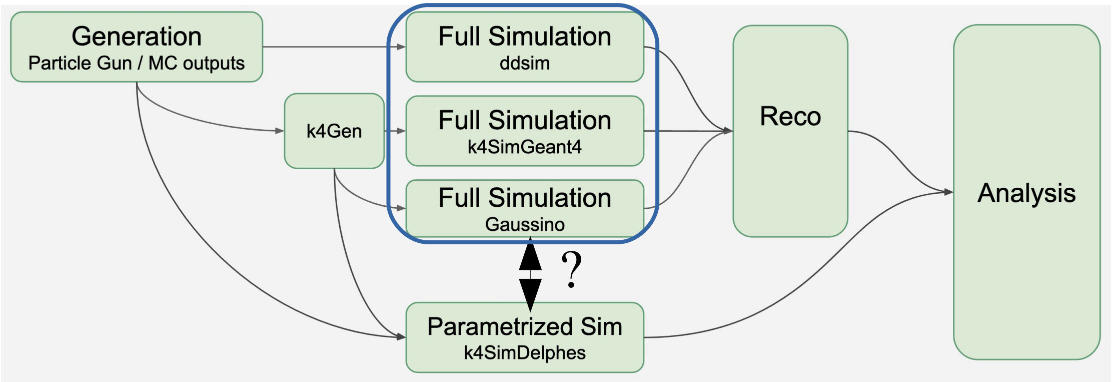
- Understand limitations of data format conversions (LCIO ↔ EDM4hep)
  - Homogenize if needed
- Homogenize full sim path**S** 'backends'
- Evaluate what time resolution we need
  - First, what can be achieved in various sub-detectors?
    - Cooling!
  - ToF based PID, 4D tracking tools, Calorimeter clustering/PFlow with timing in Key4hep



Going further (II)

Dreaming bigger

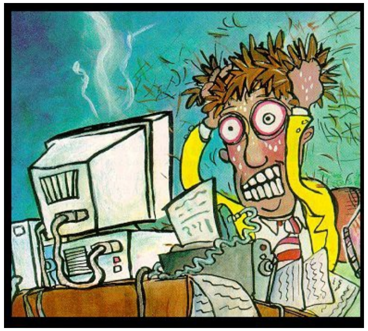
- Common reconstruction tools between detector concepts?
  - Quite challenging
    - The optimal solution always depends on the specific features of the detector
  - Stating the obvious: write reconstruction algorithm as generic as possible
    - For simple cases: optimal solution for a given detector by tuning few parameters
    - For complex cases (e.g. Particle Flow): orchestration of modular tools that each detector implementation can arrange, tune or completely overwrite
- Ease (automatize?) the translation between detector performance evaluation from full sim and parametrized simulation
  - Allows us to sweep detector free parameters, probe their comprehensive impact on physics performance



- …

Closing Words (I)

- FCC-ee FSR is not far from now
  - Many things to do, few active people
  - Prioritization!
  - Find the right balance between targeting ultimate software tools and having something that actually works, timely
- We really **need active contributions from the whole community**
  - Most people involved in FCC studies dedicate only a fraction of their time
  - Software has to be easy to use and documented
    - Challenging when trying to design very generic tools
- **Core software developers** are rarely also the **end users** → make sure we keep **strong connections** between these two groups
  - Avoid developing fancy tools that no one uses



Closing Words (II)

- Full simulation is one of the corner stone of Detector R&D
  - We are getting there but a lot of work still has to be done
    - Both on core components and on producing results with existing tools
- Working on Detector Full Sim is a great opportunity to learn both about software and detector physics
  - New contributors are warmly welcomed!
  - We are happy to provide support (FCC forum, gitHub issue, mail, coffee/beer, …)

Have a great session!


11:00 → 13:05 Joint Detector/Software

11:00 **Strategy and plans for detector software** 18m
Speaker: Brieuc Francois (CERN)

11:25 **ARC: progress update and plans towards full simulation** 18m
Speaker: Martin Tat (University of Oxford)

11:50 **Modelling signal digitisation for test calorimeters: the CALICE experience (remote)** 18m
Speaker: Vincent Boudry (LLR, CNRS, École polytechnique, Institut Polytechnique de Paris)

12:15 **Modelling signal digitisation for trackers (remote)** 18m
Speaker: Riccardo Farinelli (Universita e INFN, Ferrara (IT))

12:40 **Performance of an ALICE ITS3-like vertex detector for FCC-ee (remote) and progress on the IDEA vertex detector implementation in full simulation** 18m
Speakers: Armin Ilg (University of Zurich) , Leila Freitag (University of Zürich)