

Long Lived Particles Simulation Challenges

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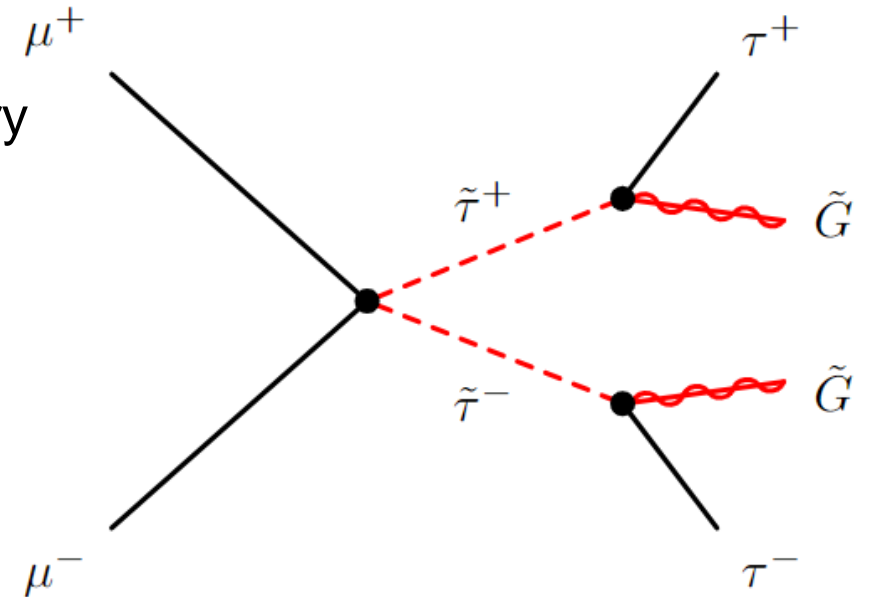
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Motivation

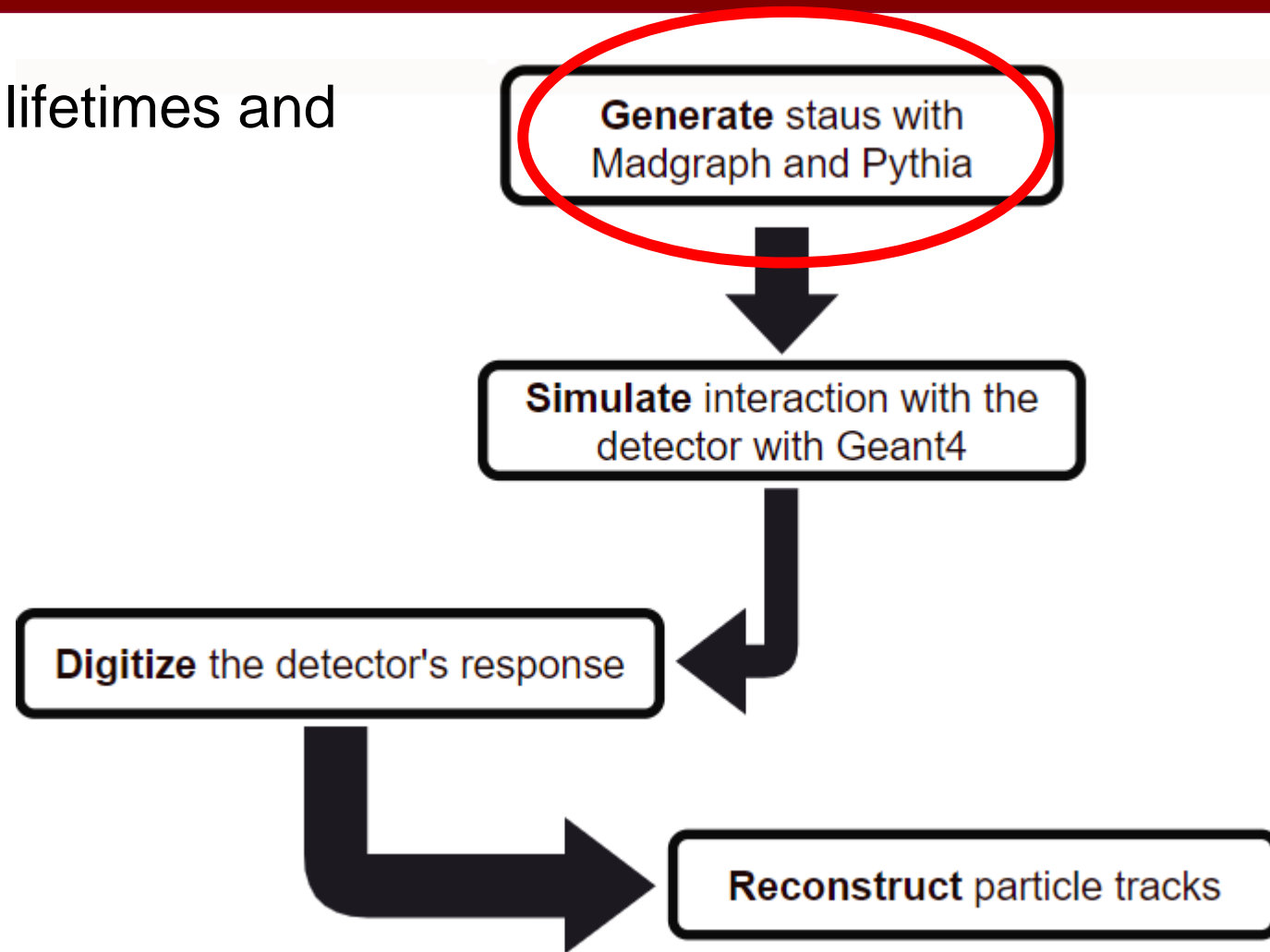
- Want to make sure we're sensitive to BSM physics
- How do BIB rejection strategies affect our ability to reconstruct displaced/slowly moving tracks from LLPs?
- In particular we will use a GMSB – gauge-mediated supersymmetry breaking – model as a benchmark that gives us multiple LLP signatures in the form of staus, the super partner of taus
 - Longer lifetimes: staus = charged LLPs
 - Shorter lifetimes: stau decay products = displaced tracks

Muons \rightarrow Staus \rightarrow Taus + Gravitinos



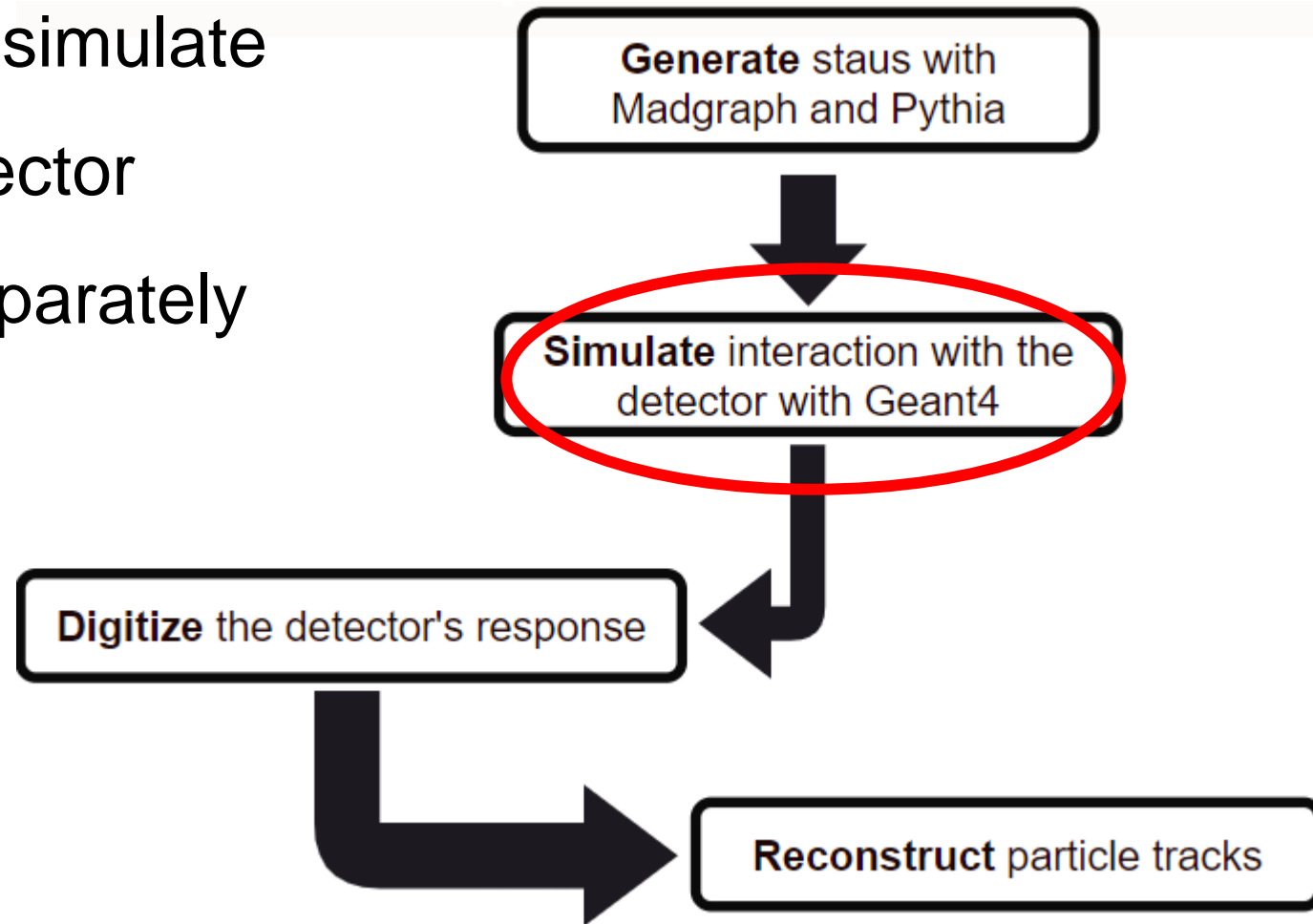
Generation

- Staus are generated with a variety of lifetimes and masses



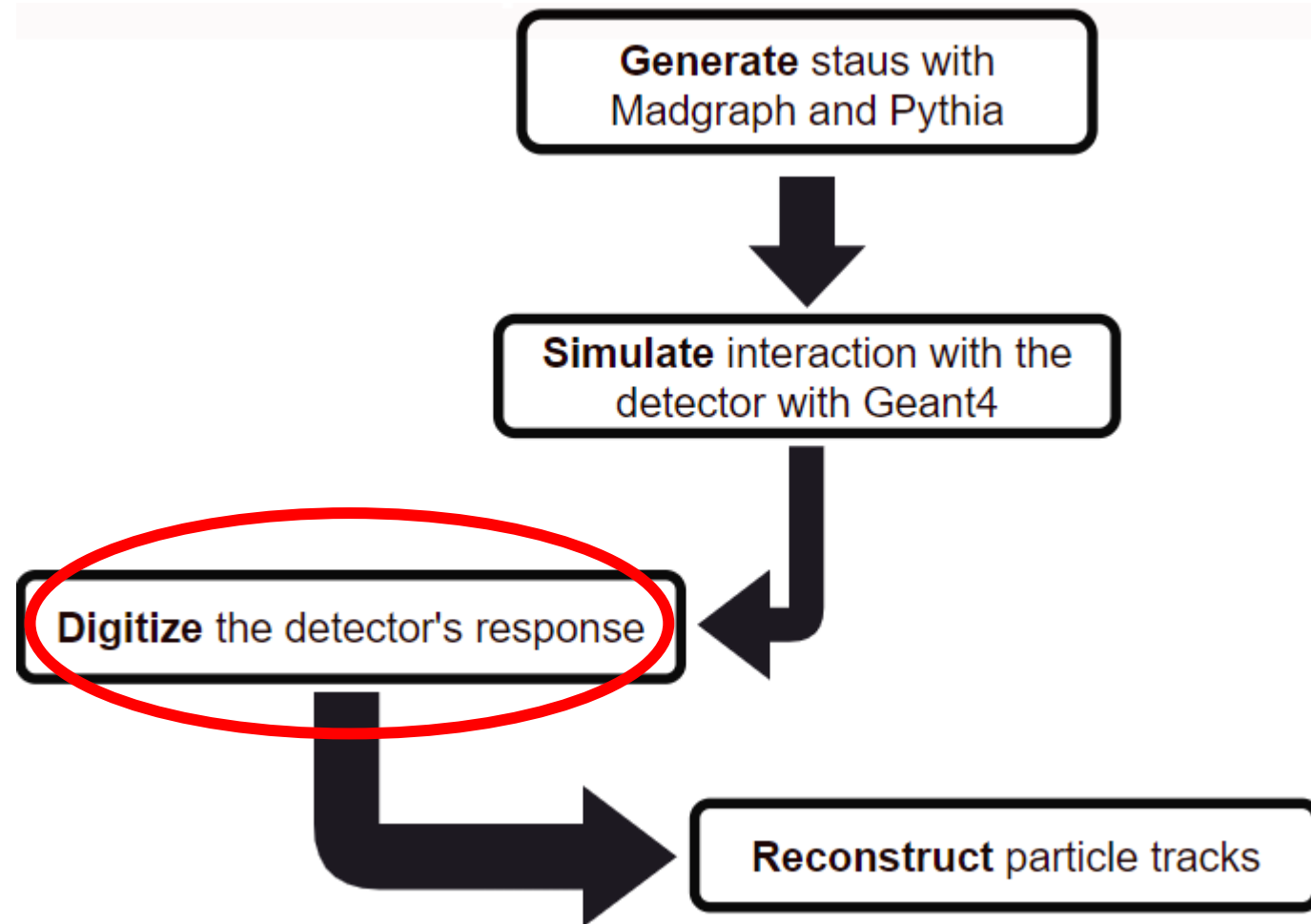
Simulation

- Use Geant4 through DD4hep to simulate interactions with the (3 TeV) detector
- BIB generated and simulated separately



Digitisation

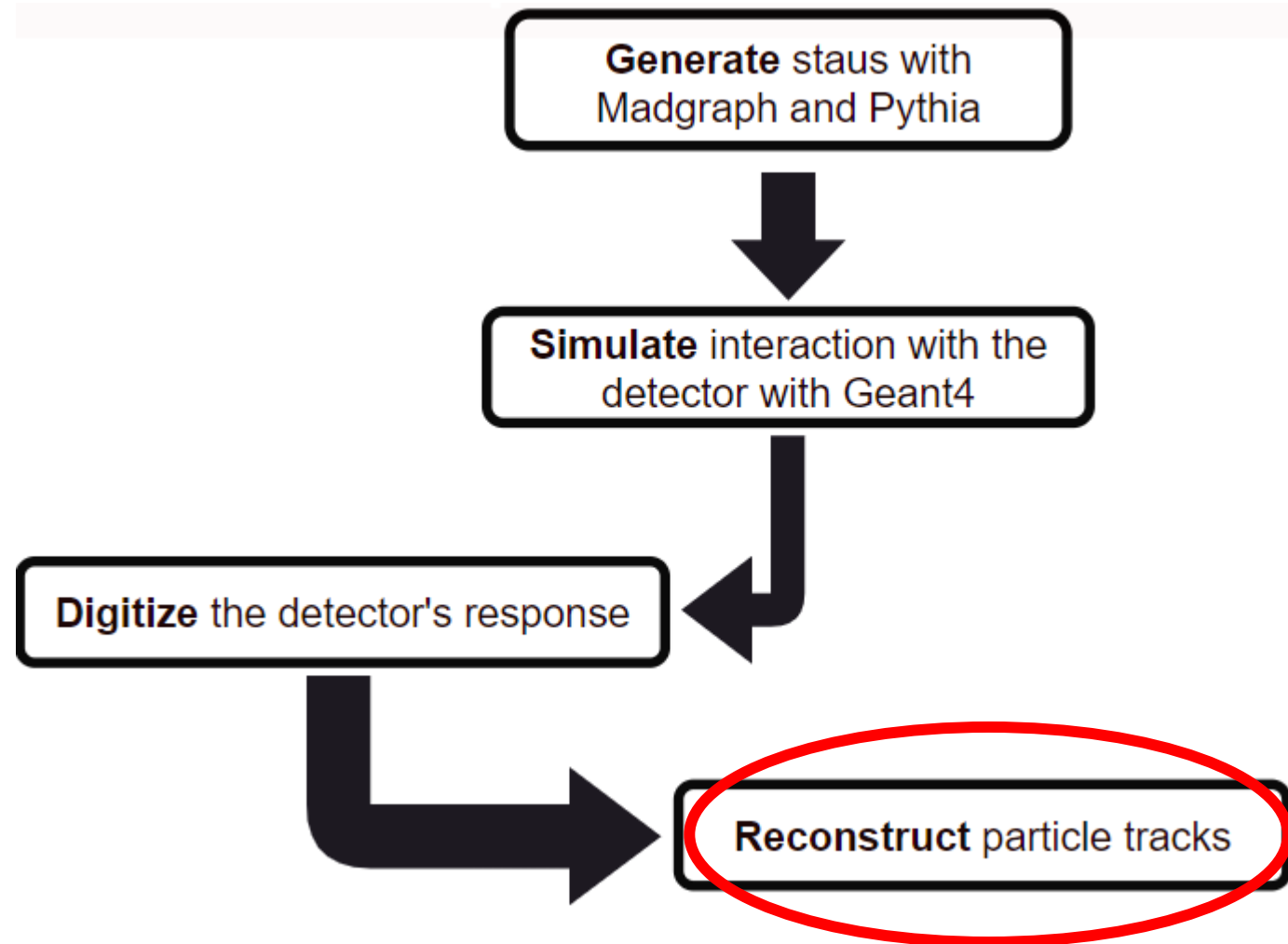
- Digi performed with Marlin
- Overlay 3 TeV BIB during digi using standard software stack from [CERN 2023 tutorial](#)



Reconstruction

Requirements for Stau tracks:

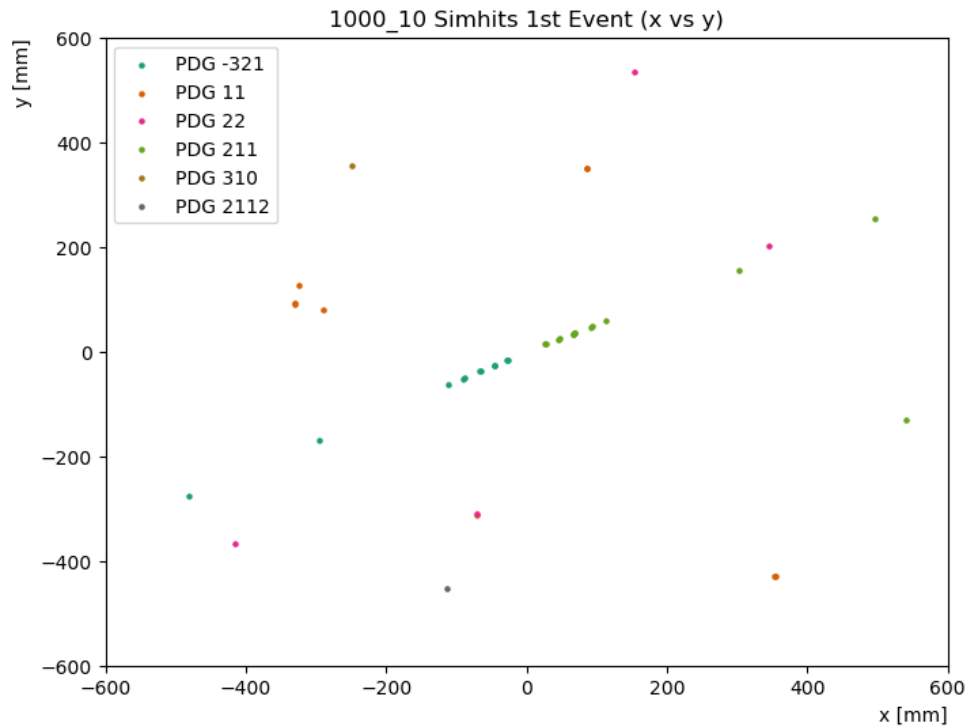
- Loosen timing window
- Loosen track impact parameter requirements
- Adapt track seeding



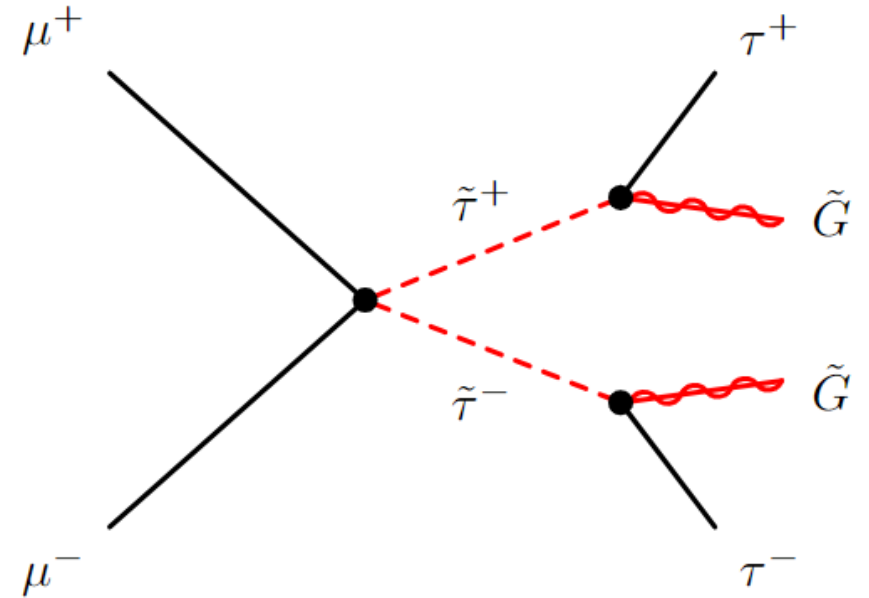
Challenges

Missing sim hits

- Realised we were not seeing stau or tau hits in sim
- Thought it might be an issue with the HepMC reader



Muons \rightarrow Staus \rightarrow Taus + Gravitinos



- When using HepMC3, no stau or tau hits AND Taus were being produced at the origin

```
Event 0
  Stau - unique id, status, endpoint: 91200 22 [4737.4092670125265, -7752.800080965485]
  Stau - unique id, status, endpoint: 91201 22 [2247.0134022316133, 3677.251574622235]
  Tau Parent - unique id, PDG: [(91200, -1000015)] Tau vertex, status: [0.0, 0.0] 2
  Tau Parent - unique id, PDG: [(91201, 1000015)] Tau vertex, status: [0.0, 0.0] 2
```

- When using HepMC2:
 - No stau or tau hits
 - Tau decay products are produced at the origin!

```
Event number: 0 Index: 0
  Stau - unique id, status, endpoint: 3514318 22 [134.3503917470852, 76.3458366732759]
  Stau - unique id, status, endpoint: 3514319 22 [192.33741450622148, -109.29749175346733]

  Tau Parent - unique id, PDG: [(3514318, -2000015, [116.29957262418267, 67.26393662303542, 76.3458366732759])]
  Tau - unique id, vertex, endpoint, status, : 3514321 [134.3503917470852, 76.3458366732759] [248.70077586655816, 120.52146887015729] 2
    Tau decay products - unique id, PDG, status, prod_vertex:
      (3514324, -16, 1, [0.0, 0.0, 0.0])
      (3514325, 111, 2, [0.0, 0.0, 0.0])
      (3514326, 111, 2, [0.0, 0.0, 0.0])
      (3514327, 211, 1, [0.0, 0.0, 0.0])

  Tau Parent - unique id, PDG: [(3514319, 2000015, [-166.49567460006404, -96.29574943063503, -109.29749175346733])]
  Tau - unique id, vertex, endpoint, status, : 3514323 [192.33741450622148, -109.29749175346733] [328.8536773070865, -126.2446109118547] 2
    Tau decay products - unique id, PDG, status, prod_vertex:
      (3514328, 16, 1, [0.0, 0.0, 0.0])
      (3514329, 311, 2, [0.0, 0.0, 0.0])
      (3514330, -321, 1, [0.0, 0.0, 0.0])
```

Status Code Issue

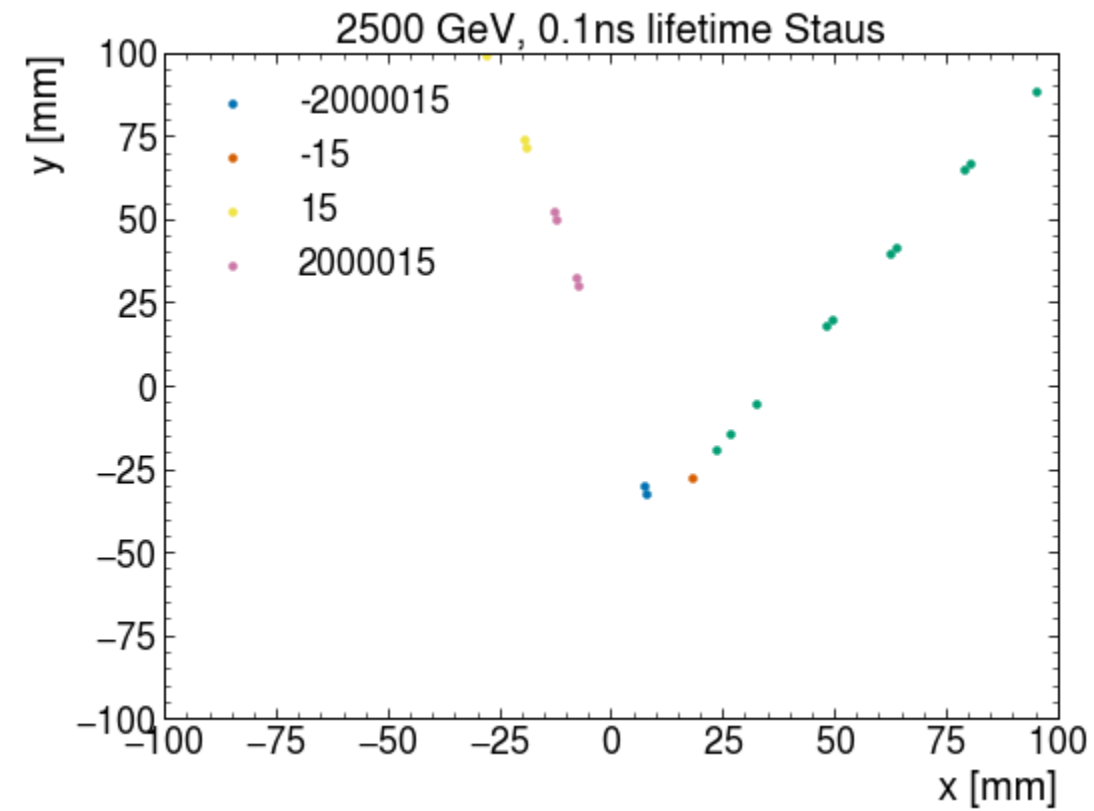
- Discussed with the DD4hep team [here](#)
 - HepMC3 can read hepMC2 generated files
 - The HepMC2 reader that is implemented in DD4hep doesn't work for secondary vertices
 - DDsim will not pass anything to Geant4 with generator status > 2 (but [Pythia](#) produces particles with lots of status codes!)
- Can try changing status from 22 \rightarrow 2 but ...
 - When taus instantly emit a photon they have different status codes:
 - 51 : outgoing produced by parton branching
 - 52 : outgoing copy of recoiler, with changed momentum
 - Taus also had status > 2 in some cases!

Status Code Issue

- Very quickly a feature was [merged](#) into main branch
 - Can now set alternative decay statuses to pass into Geant4
- Eventually got it working using the following configuration in the SIM steering file:
 - `SIM.physics.alternativeDecayStatuses = {22, 23, 51, 52}` # 22, 51, 52 are staus; 23 is taus
 - `SIM.physics.zeroTimePDGs = {17, 11}`
 - `SIM.physics.rejectPDGs = {1,2,3,4,5,6,21,23,24,25,1000049}` # added gravitinos to this list

Conclusions

- We can now see stau and tau hits in sim!
- We have also successfully run digi and reco
- Next Steps:
 - Verify we see stau tracks in reco
 - Adjust track seeding to boost reconstruction efficiency
 - Add BIB to see if reco is robust
 - Iterate



Backup

Sample

- Staus produced at $m = 1000$ GeV, lifetime = 0.1ns
- hepmc installation log in madgraph was hepmc2.06.09
- dd4hep-1.25.1



Tracing a Particle

Intermediate particle - unique id, pdg, status, vertex, endpoint: 3272938 -321 1 [0.0, 0.0, 0.0] [-1513.3715701401975, -869.4551654509879, -216.2230909655218]

Intermediate particle - unique id, pdg, status, vertex, endpoint: 3272931 15 2 [-166.49567460006404, -96.29574943063503, -109.29749175346733] [-285.04215978671095, -163.9991104321012,

Intermediate particle - unique id, pdg, status, vertex, endpoint: 3272927 2000015 22 [0.0, 0.0, 0.0] [-166.49567460006404, -96.29574943063503, -109.29749175346733]

MUON COLLISION

- Top particle (K-) we trace back to see the full decay chain
- K- ← Tau ← Stau ← muon collision
- Tau is now produced at the endpoint of the stau 
- **K- is produced at the origin!** 
- This is, in fact, true of ALL tau decays!

Tau Decay Products

Event number: 0 Index: 0

Stau - unique id, status, endpoint: 3514318 22 [134.3503917470852, 76.3458366732759]

Stau - unique id, status, endpoint: 3514319 22 [192.33741450622148, -109.29749175346733]

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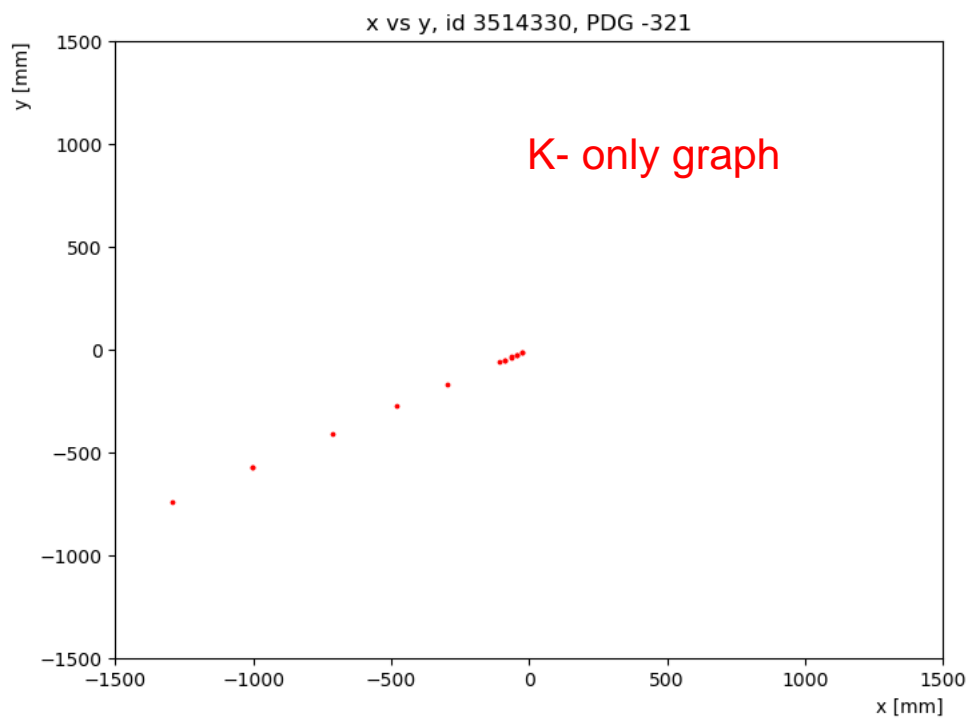
(3514329, 311, 2, [0.0, 0.0, 0.0])

(3514330, -321, 1, [0.0, 0.0, 0.0])

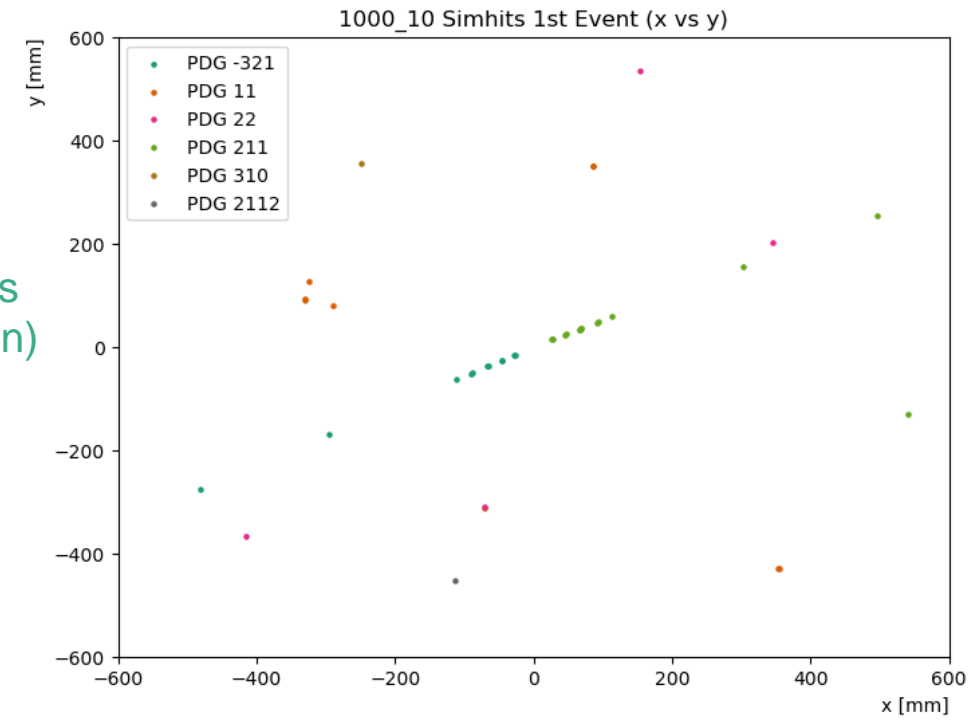
- 2 staus \rightarrow 2 taus \rightarrow neutrinos + Kaons + Pions
- All decay products are produced at the origin!

Sim Hits

- We see the K- (-321) coming from the origin and moving to the bottom left
- Clearly demonstrates that the simulation thinks the particle is in the wrong place, it's not just a problem with the storage
- There are also NO stau OR tau hits detected: `Unique pdgs [-321 11 22 211 310 2112]`

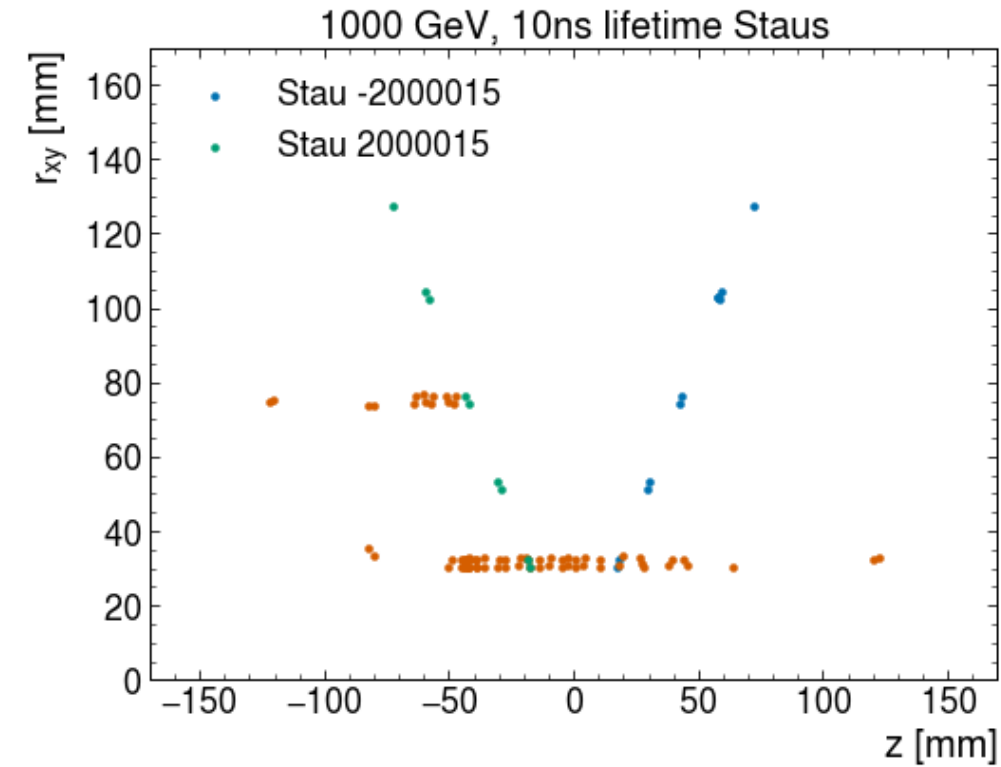
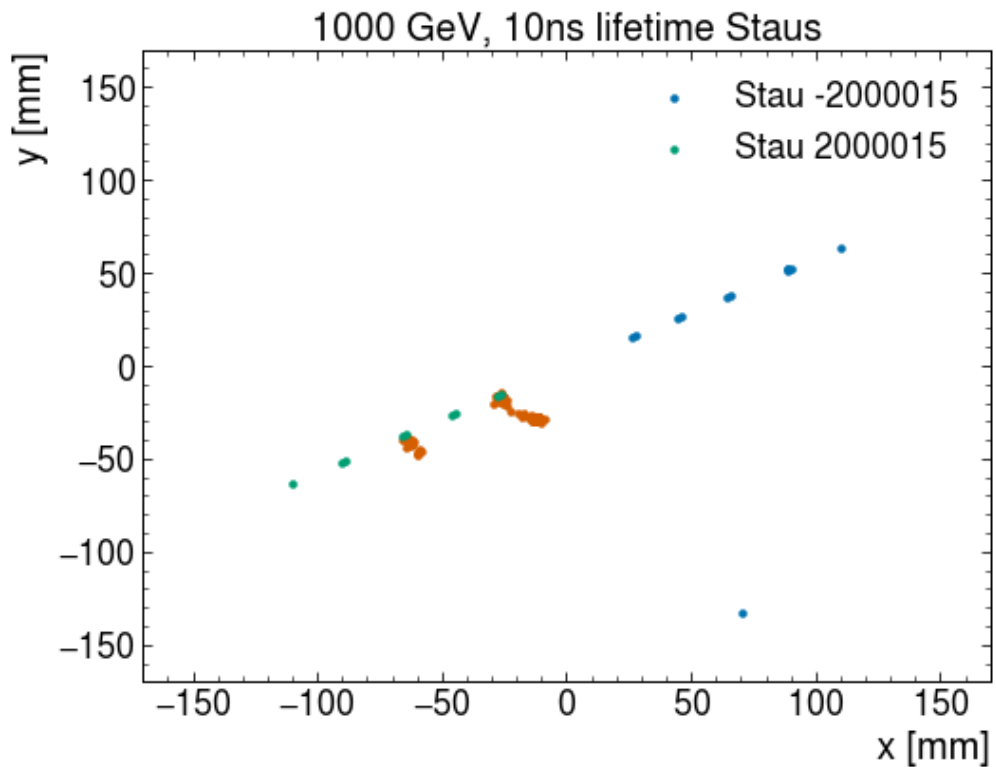


All particles
(K- in green)



Stau Hits

- We are beginning to be able to see stau hits in simulation but not for every situation – iterating with dd4hep personnel



Next Steps

- Once we have all particles properly simulated, we can move on and ensure we are able to reconstruct the tracks
- With tracks properly reconstructed for signal samples, we can then add BIB and see if our track reconstruction is robust enough to handle the large amount of background