Geant4e Track Extrapolation in the (Super)Belle Experiment

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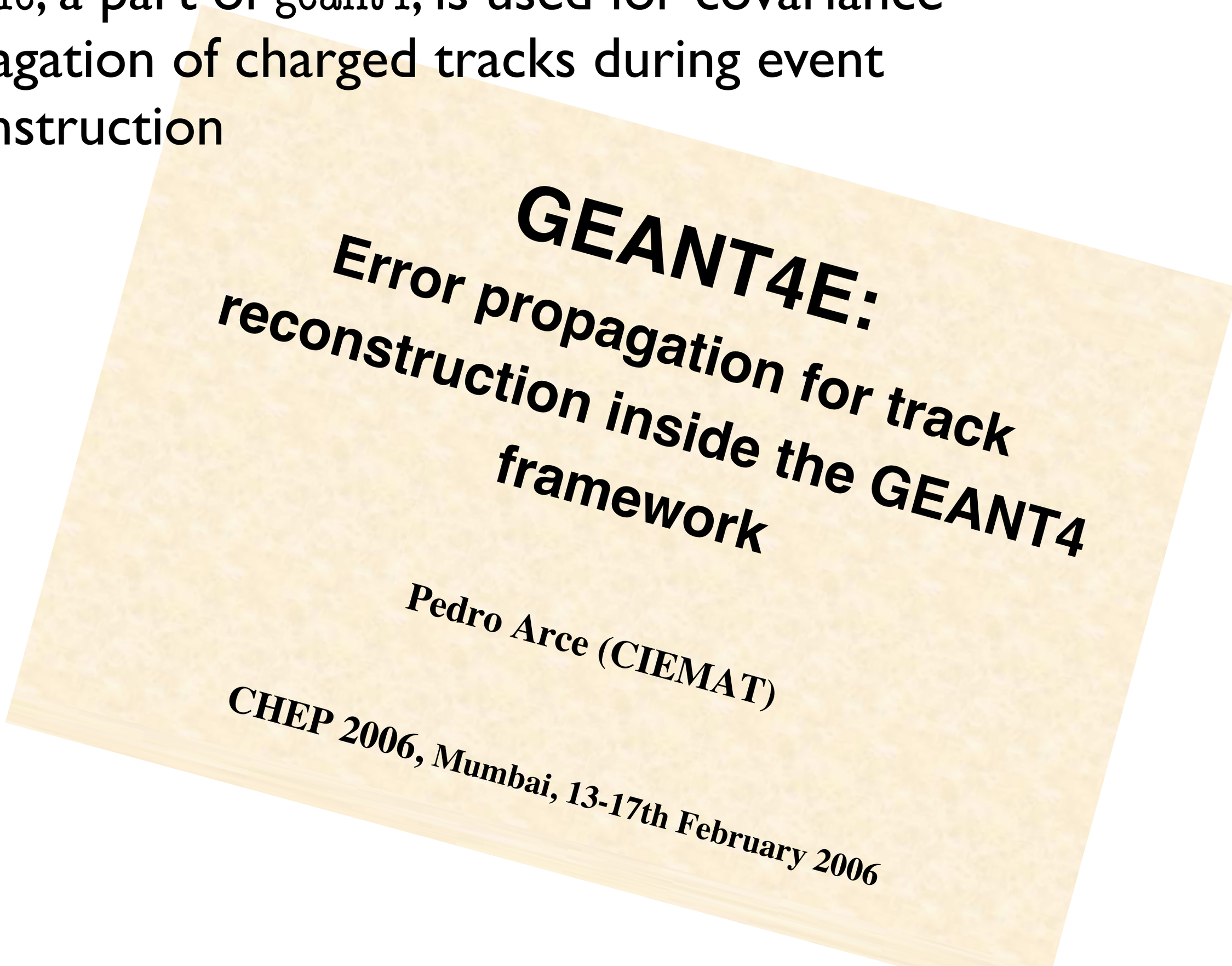
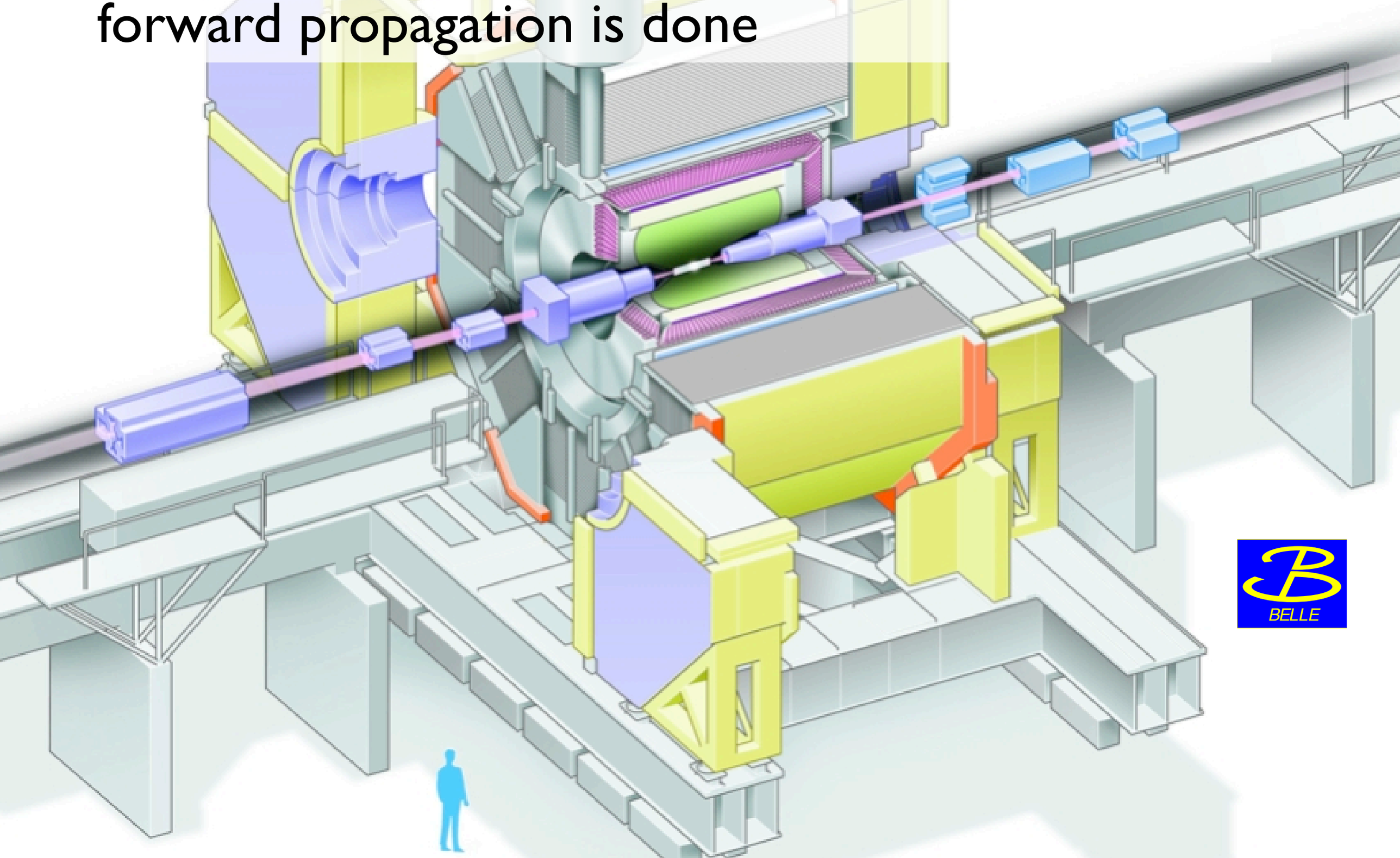
geant4e, a part of geant4, is used for covariance propagation of charged tracks during event reconstruction

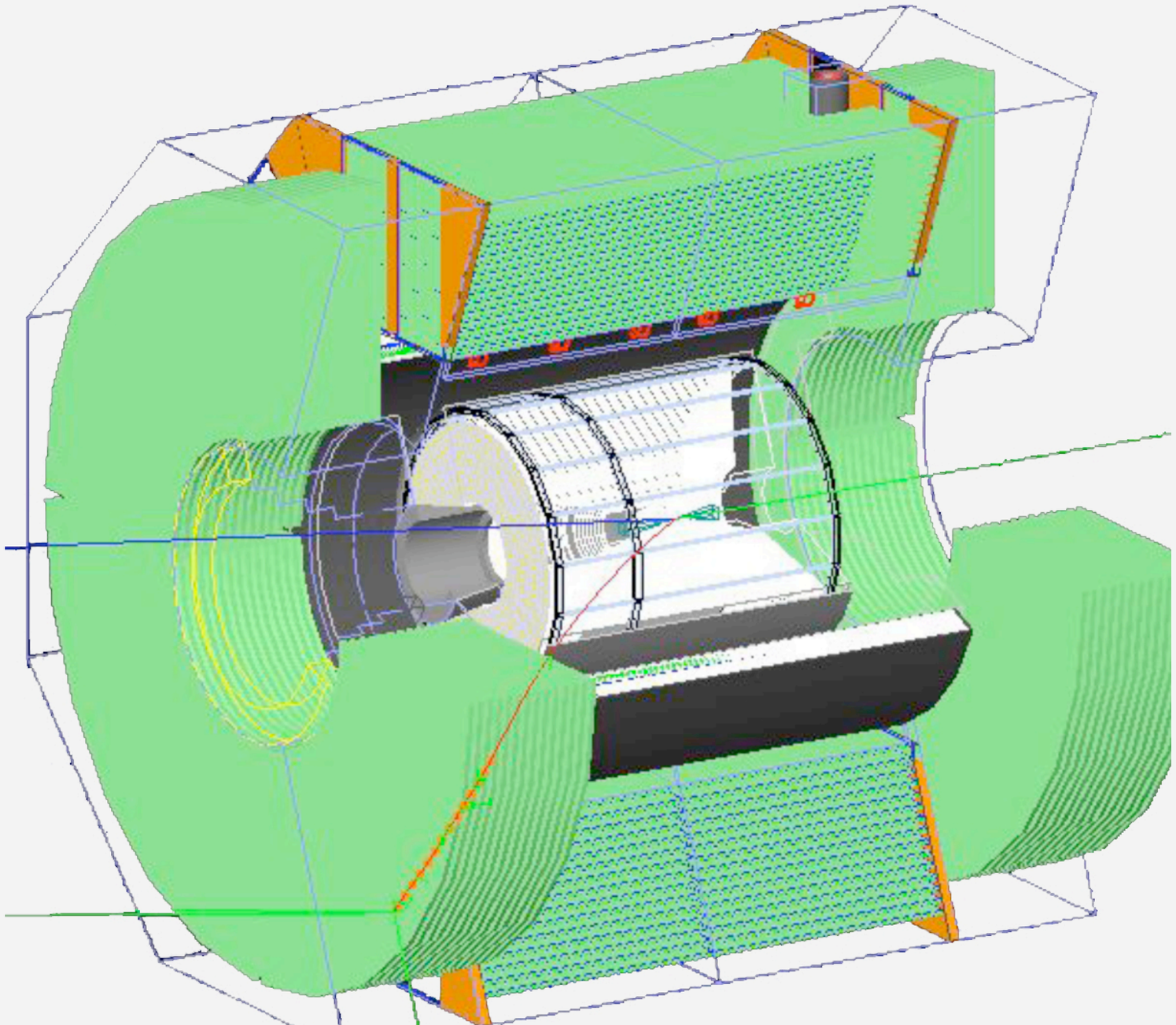


In (Super)Belle, use `geant4e` for track propagation and muon identification during event reconstruction; only forward propagation is done



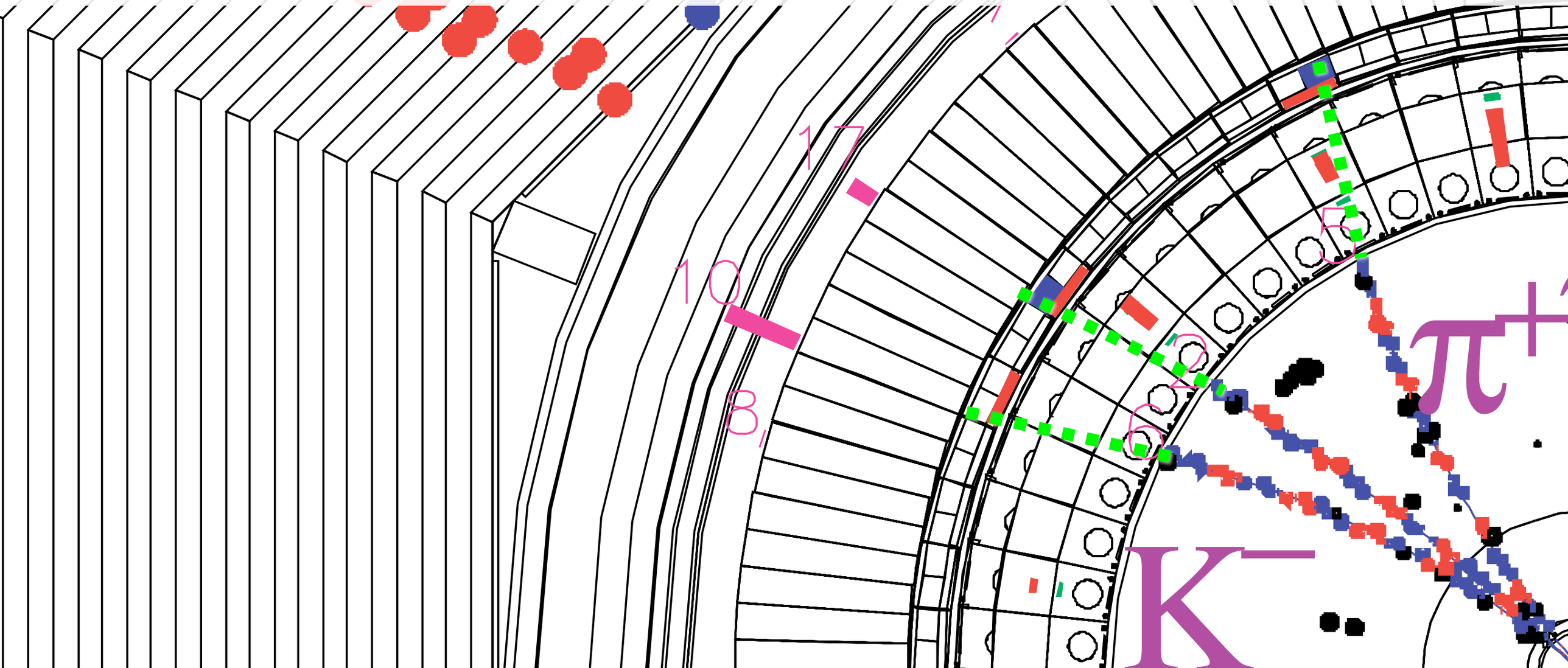
geant4 model of the (Super)Belle detector:

- ☑ complete subdetector geometry
- ☑ non-uniform solenoidal magnetic field (~1.5 T)
- ☑ common geometry for geant4 and geant4e



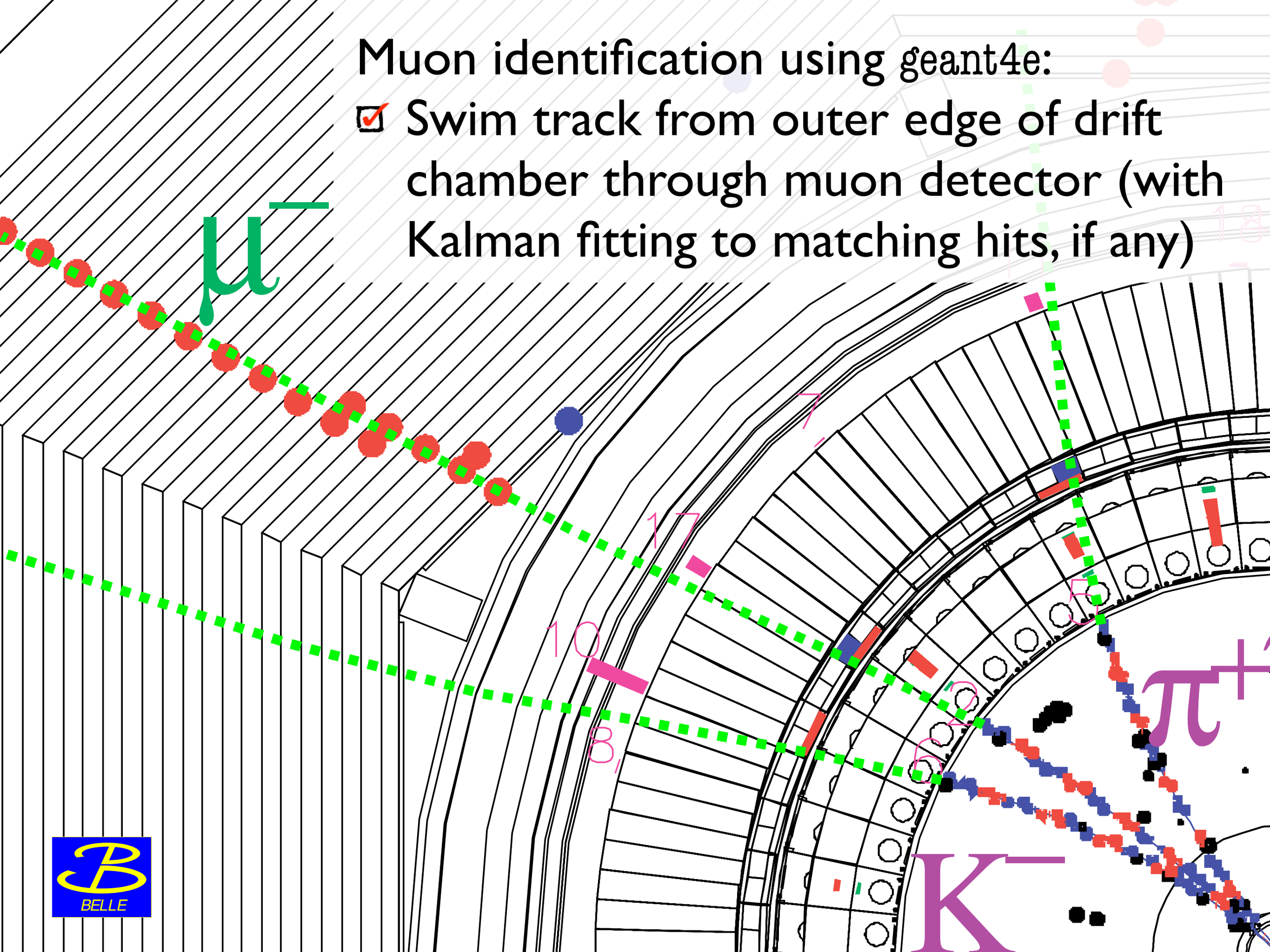
Charged track extrapolation using geant4e:

- ☑ For each of 5 hypotheses $e,\ \mu,\ \pi,\ K,\ p$ ...
- ☑ swim each track from outer edge of drift chamber to calorimeter face [or muon detector face for π]
- ☑ store position, momentum and covariance matrix at entrance/exit of selected volumes



Muon identification using geant4e:

- ☑ Swim track from outer edge of drift chamber through muon detector (with Kalman fitting to matching hits, if any)



We have two usage modes of `geant4e`:

- ☑ for real events:
  standalone
- ☑ for simulated events:
  in combination with `geant4`, since we do simulation and reconstruction in one pass

But `geant4e`, as distributed, cannot coexist with `geant4`:

- ☐ distinct particle lists
- ☐ distinct physics processes
- ☐ conflicting usage of common detector geometry
- ☐ distinct states when calling `RunManager`
- ☐ distinct user actions (`SteppingAction` etc)

We have resolved these issues ...

Particles and Physics Processes:

- PhysicsList is a concrete implementation of G4VUserPhysicsList, and must define:
  - ConstructParticle()
  - ConstructProcess()
  - SetCuts()

- geant4 and geant4e require different PhysicsLists.

- Lots of overhead to change PhysicsList when switching between geant4 and geant4e, so avoid this!

Particles and Physics Processes, cont'd:

- Define a combined PhysicsList
  - ConstructParticle() defines gamma e+ e– mu+ mu– pi+ pi– pi0 kaon+ kaon– kaon0 kaon0L kaon0S proton anti_proton neutron anti_neutron geantino chargedgeantino opticalphoton etc., as well as g4e_e+ g4e_e– g4e_gamma g4e_mu+ g4e_mu– g4e_proton g4e_pi+ g4e_pi– g4e_kaon+ g4e_kaon– with PIDcode = 1000000000 + stdPIDcode

Particles and Physics Processes, cont'd:

- Define a combined PhysicsList (cont'd)
  - For standard particles, ConstructProcess() does AddTransportation(), ConstructDecayProcess(), ConstructEMProcess(), ConstructHadronicProcess(), and ConstructOpticalPhotonProcess(), as appropriate
  - For "g4e" particles, ConstructProcess() does only AddTransportation() and ConstructEMProcess(); the latter defines ionization energy loss as the sole physics process for charged particles.

Particles and Physics Processes, cont'd:

- Define a combined PhysicsList (cont'd)
  - For standard particles, SetCuts() does SetCutsWithDefault() using default = 1.0*mm
  - For g4e particles, SetCuts() does SetCutsWithDefault() using default = 1.0E9*cm

Common Detector Geometry:

- SteppingManager in geant4 calls user code to process steps through "sensitive" detector volumes and record hits therein.
- This behaviour is undesirable in the geant4e context.
- For "g4e" particles, ConstructEMProcess() adds a new NoHits() process:

```
G4ParticleChange particleChange;
G4VParticleChange* NoHits::PostStepDoIt( const G4Track& track, const G4Step& )
{
 particleChange.Initialize( track );
 particleChange.ProposeSteppingControl( AvoidHitInvocation );
 return &particleChange;
}
```

geant4e "Target" Geometry:

- Beyond the standard detector geometry, `geant4e` prescribes a "target" surface: `geant4e` terminates the track propagation when the track crosses this surface.
- The available surfaces are not adequate for our needs.

- Duplicate then modify `G4ErrorCylSurfaceTarget` so that it includes the cylinder endcaps.

Distinct Run States and User Actions:

- During job initialization, detect presence of geant4 by non-empty G4PhysicalVolumeStore. If co-existing, do G4StateManager::GetStateManager()->SetNewState(G4State_Idle) after InitGeant4e(), then save UserTrackingAction and UserSteppingAction.
- During processing of one event:

```
if ( geant4e is running with geant4 ) {
  hide UserTrackingAction and UserSteppingAction;
}
extrapolate all tracks in the event using “g4e” particles;
if ( geant4e is running with geant4 ) {
  restore UserTrackingAction and UserSteppingAction;
}
```

Distinct Run States, cont'd:

- Duplicate and modify G4ErrorPropagationNavigator so that it exhibits the geant4e behaviour during track propagation

```
g4edata != 0 &&
g4edata->GetState() == G4ErrorState_Propagating
```

  or the geant4 behaviour otherwise.

G4**Navigator has two methods – ComputeStep and ComputeSafety – to determine distance to volume boundary. While geant4e is active, the distance to the "target" surface is included in these calculations.

Conclusion:

In the (Super)Belle software library, we have succeeded in implementing `geant4e` for track propagation and muon identification during event reconstruction, either standalone or in conjunction with `geant4` event simulation:

- ☑ merged particle list including "`g4e`" particles
- ☑ distinct physics processes for "`g4e`" particles
- ☑ no hit invocation in sensitive volumes for `geant4e`
- ☑ distinct states and user actions during event processing