Simulation of dark photon generation process $e^- Z \rightarrow e^- Z A'$ for NA64 experiment using Geant4

Search for dark sectors in missing energy events

On behalf of NA64 collaboration

NA64 collaboration

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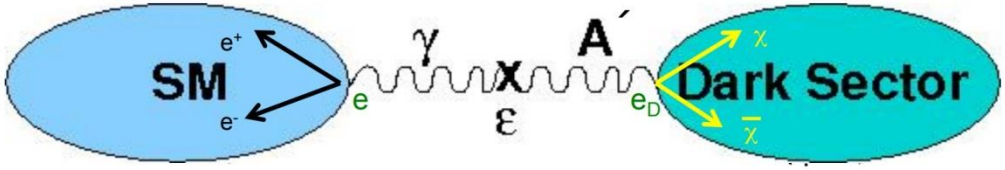
49 researchers from 12 Institutes

“Portal” to dark sector



B. Holdom, Phys. Lett. B **166**, 196 (1986).

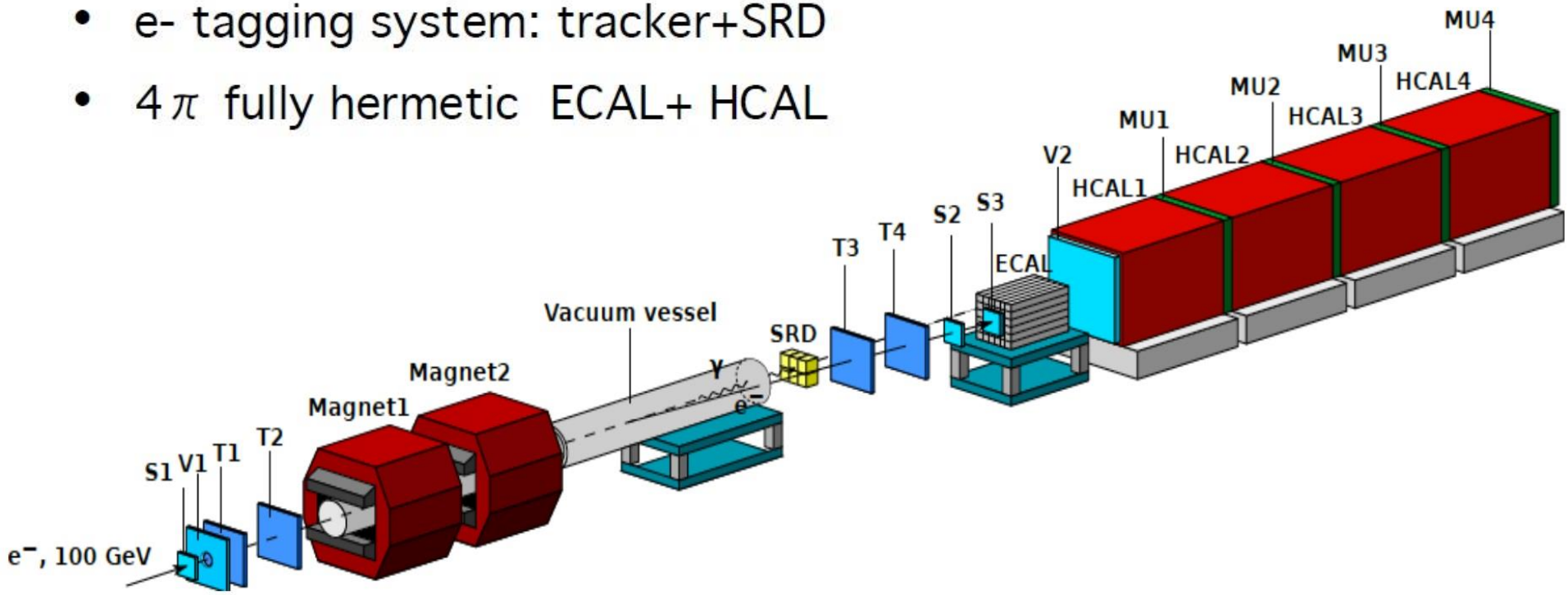
L. B. Okun, “Limits Of Electrodynamics: Paraphotons?,” Sov. Phys. JETP **56**, 502 (1982) [Zh. Eksp. Teor. Fiz. **83** 892 (1982)].

- DM can be probed only through its gravitational interaction
- a new force between the dark sector and visible matter transmitted by a new vector boson A0 (dark photon) might exist
- A' could have a mass $m_A, \lesssim 1\ GeV$
- associated with a spontaneously broken gauged $U(1)_D$ symmetry
- Coupled to SM photon via kinetic mixing term $-\frac{1}{2}\varepsilon\, F_{\mu\vartheta}A'^{\mu\vartheta}$ $\varepsilon << 1$

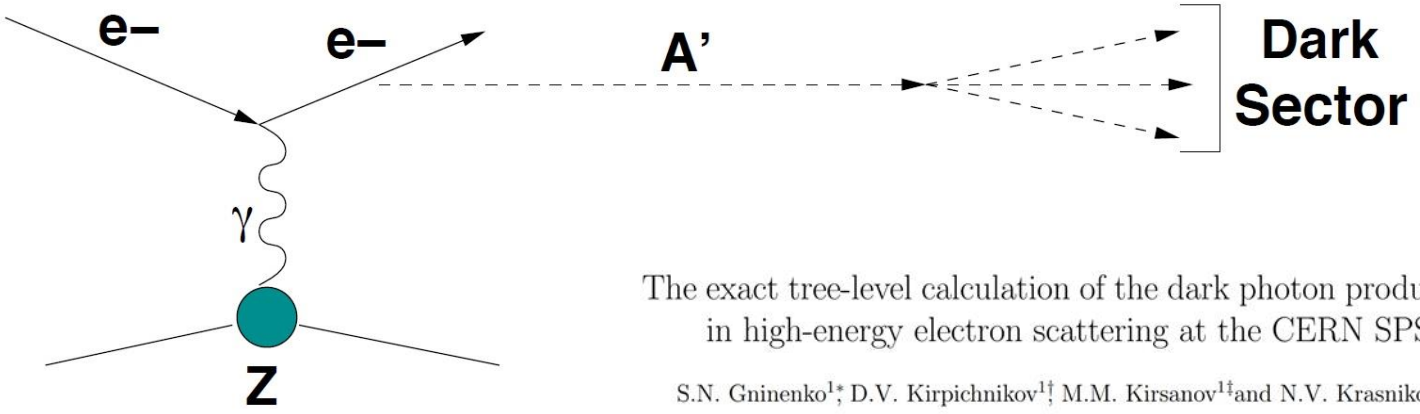
Experimental setup

Main components :

- clean 100 GeV e- beam
- e- tagging system: tracker+SRD
- 4π fully hermetic ECAL+ HCAL



Main process



The exact tree-level calculation of the dark photon production in high-energy electron scattering at the CERN SPS

S.N. Gninenko[1]*, D.V. Kirpichnikov[1]†, M.M. Kirsanov[1‡]and N.V. Krasnikov[1,2§]

- NA64 active dump setup
- Electron tagging with SRD
- Shower development inside ECAL
- Possible dark photon production

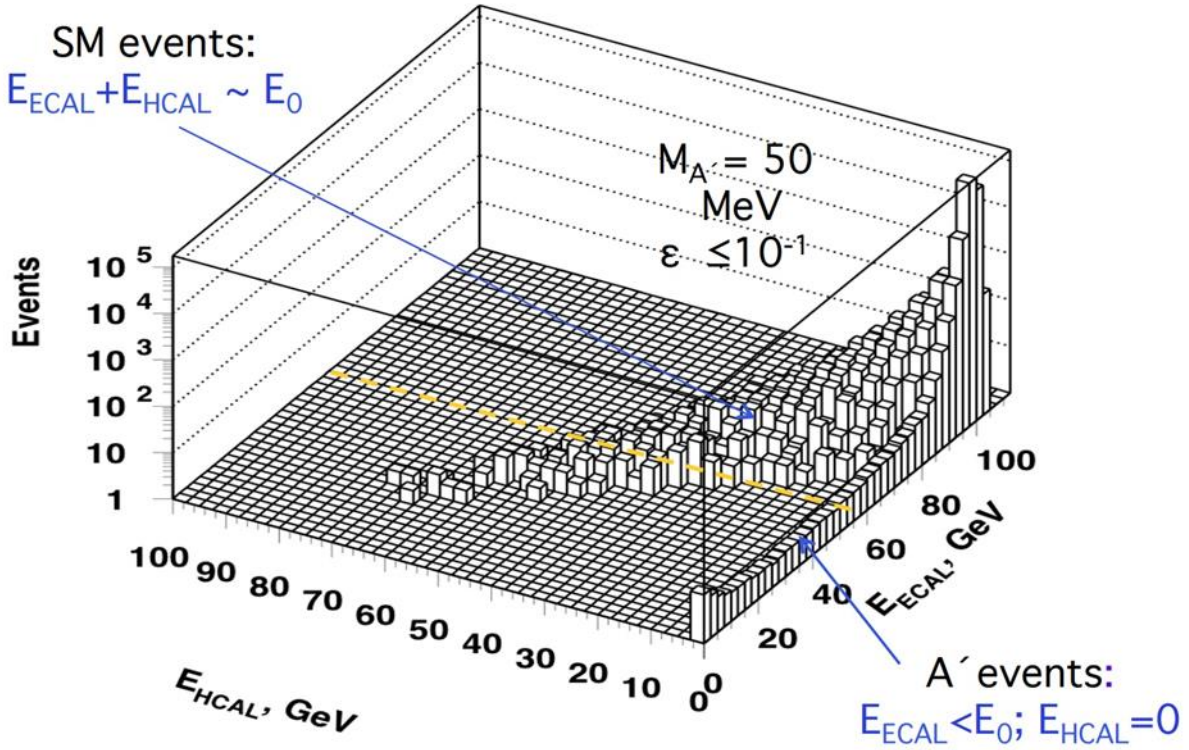
Signature:

- in: 100 GeV e- track
- out: $E_{ECAL} < E_0$ shower in ECAL
- no energy in Veto and HCAL

Background:

- μ, π, K decays in flight
- Tail < 50 GeV in the e- beam
- Energy leak from ECAL+HCAL

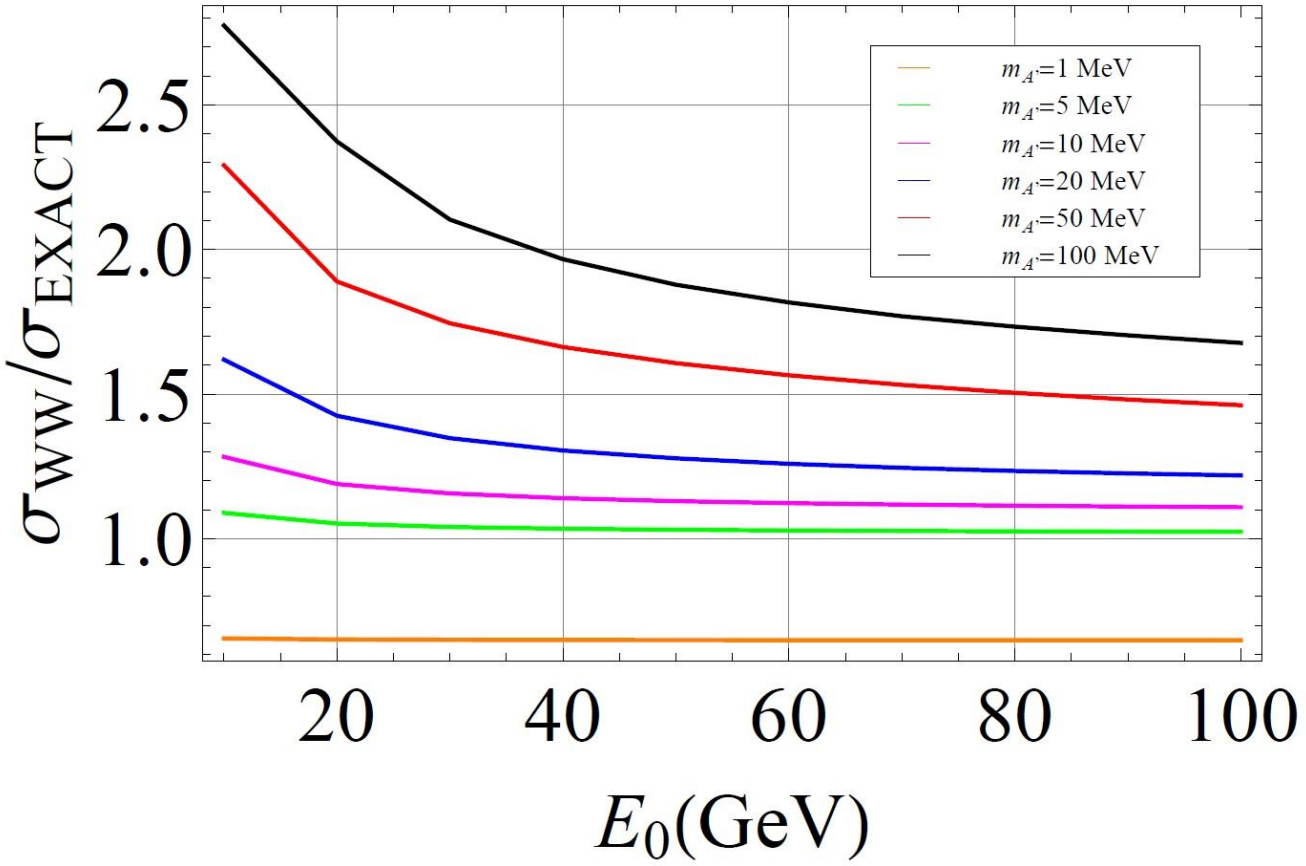
Method of search and signatures



- Invisible mode
- A' produced via kinetic mixing by bremsstrahlung photons inside active beam target
- Prompt decay to invisible dark particles
- Fraction of beam energy carried away $E_{A'} = f * E_0$
- Remaining part is deposited
- Signature
  - Missing energy
  - Isolated EM shower with energy less than E_0

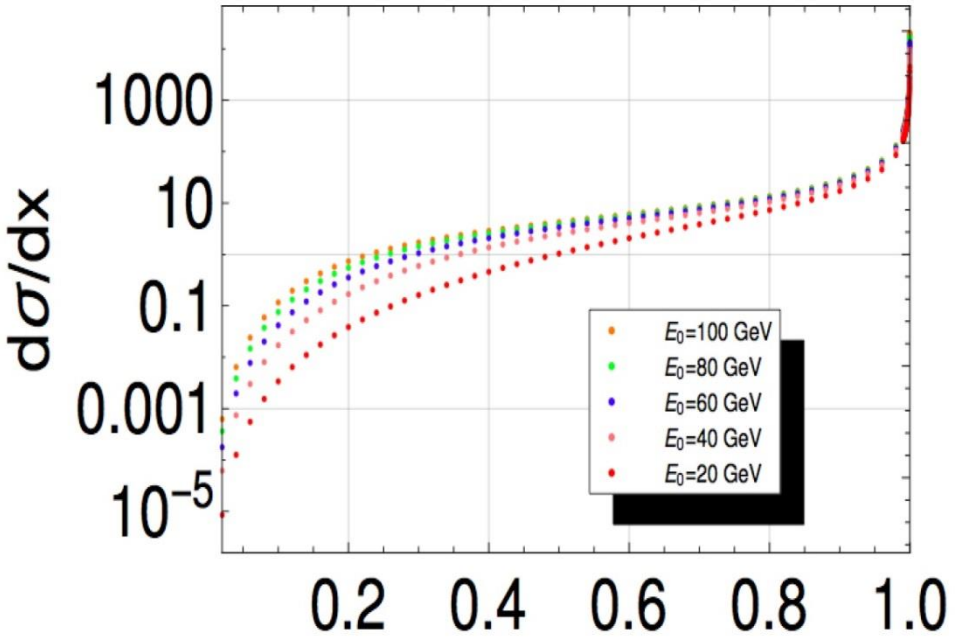
Simulation signatures

- Weizsaaecker-Williams (WW) approximation (Bjorken et al., 2009)
- Exact Tree Level calculations performed (Phys Lett B, arXiV:1712.05706)
- So called K-factors introduced to the total CS calculation
- CS can be decreased by factor 15 compared to simplified WW at $m_A, \sim 1\ GeV$



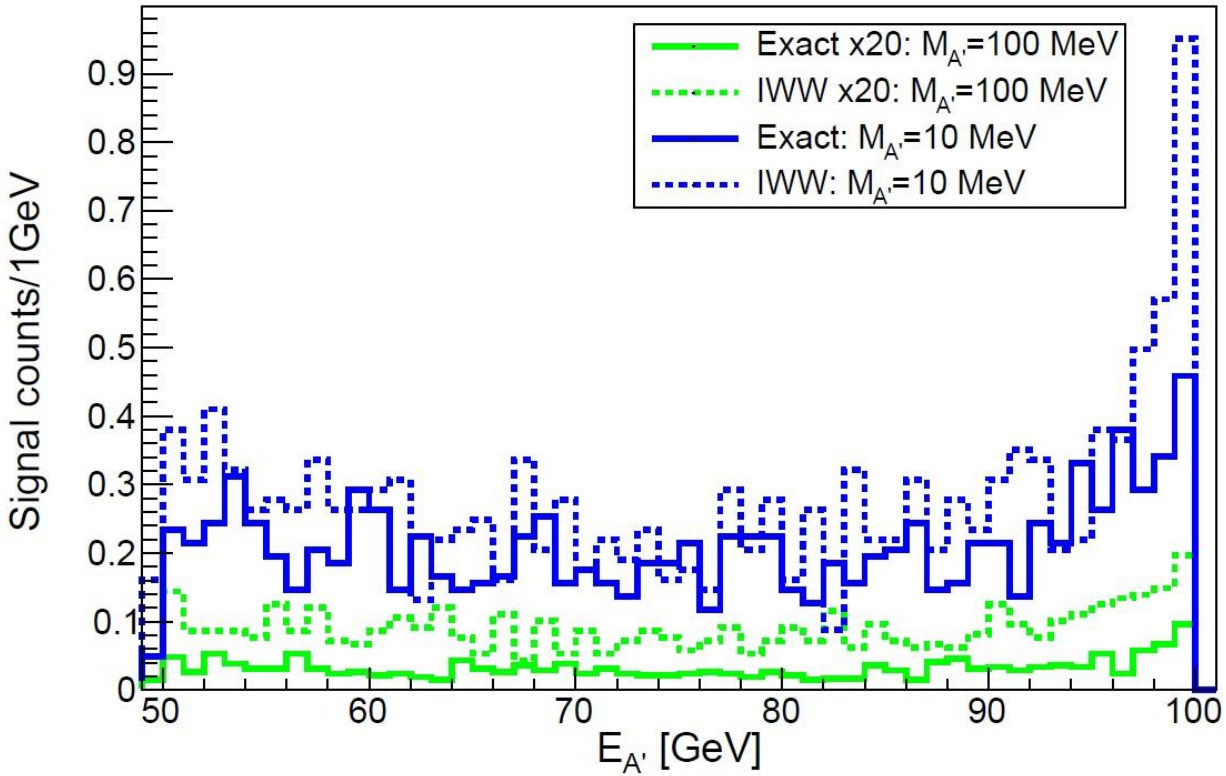
Geant4 implementation

- EM shower development is simulated in MC package for NA64
- Total and differential cross sections caculated on each geant4 step
- If emission is accepeted - angular characteristics of resulting partcle are manually generated
- Calculation of 4-momentum of recoil electron
- K-factor implemented



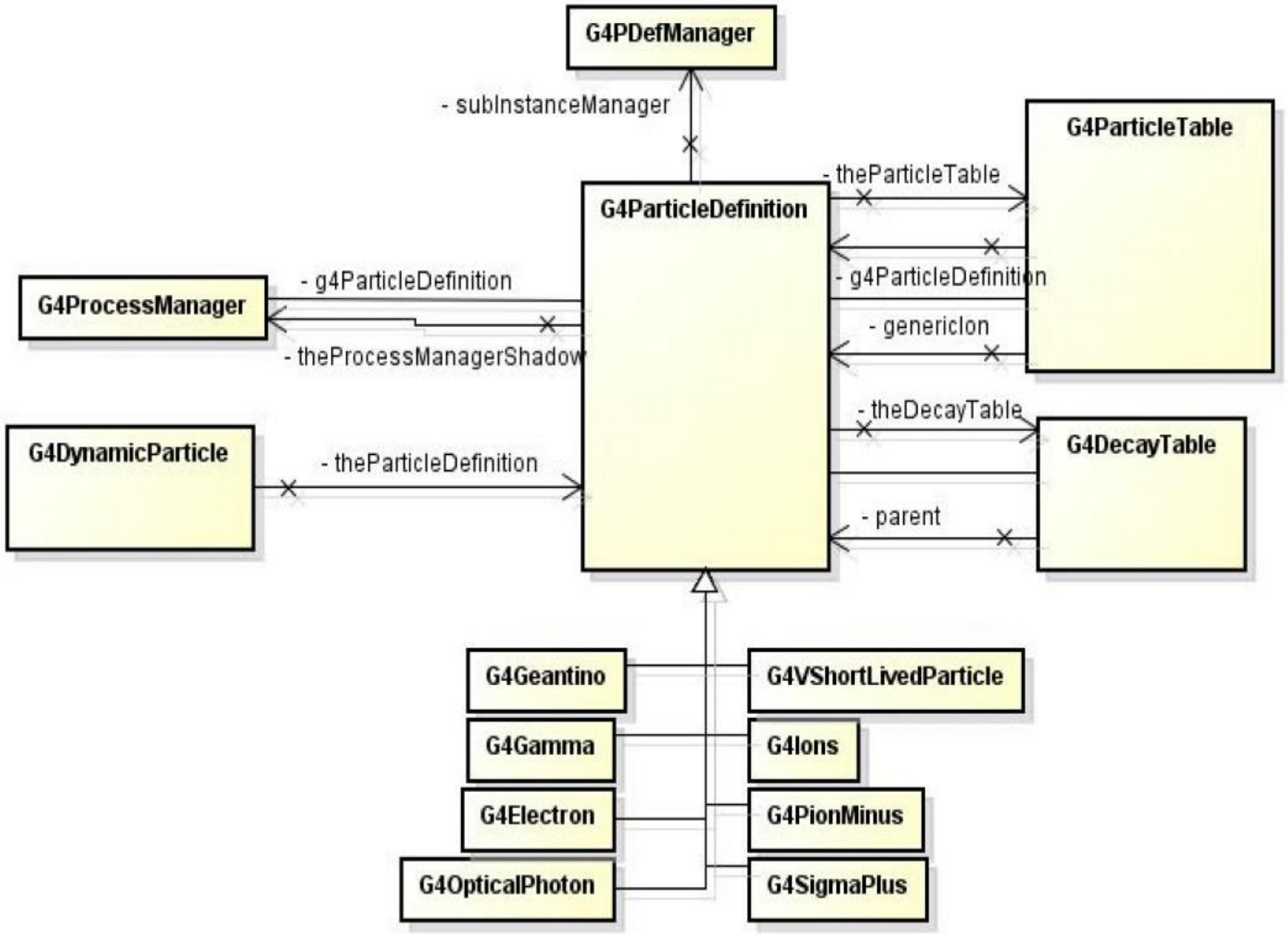
Geant4 implementation

- Emission spectra for A’ is simulated
- Visible mode
- Decay e^+/e^- are tracked through the medium
- Bremsstrahlung gamma, conversion,

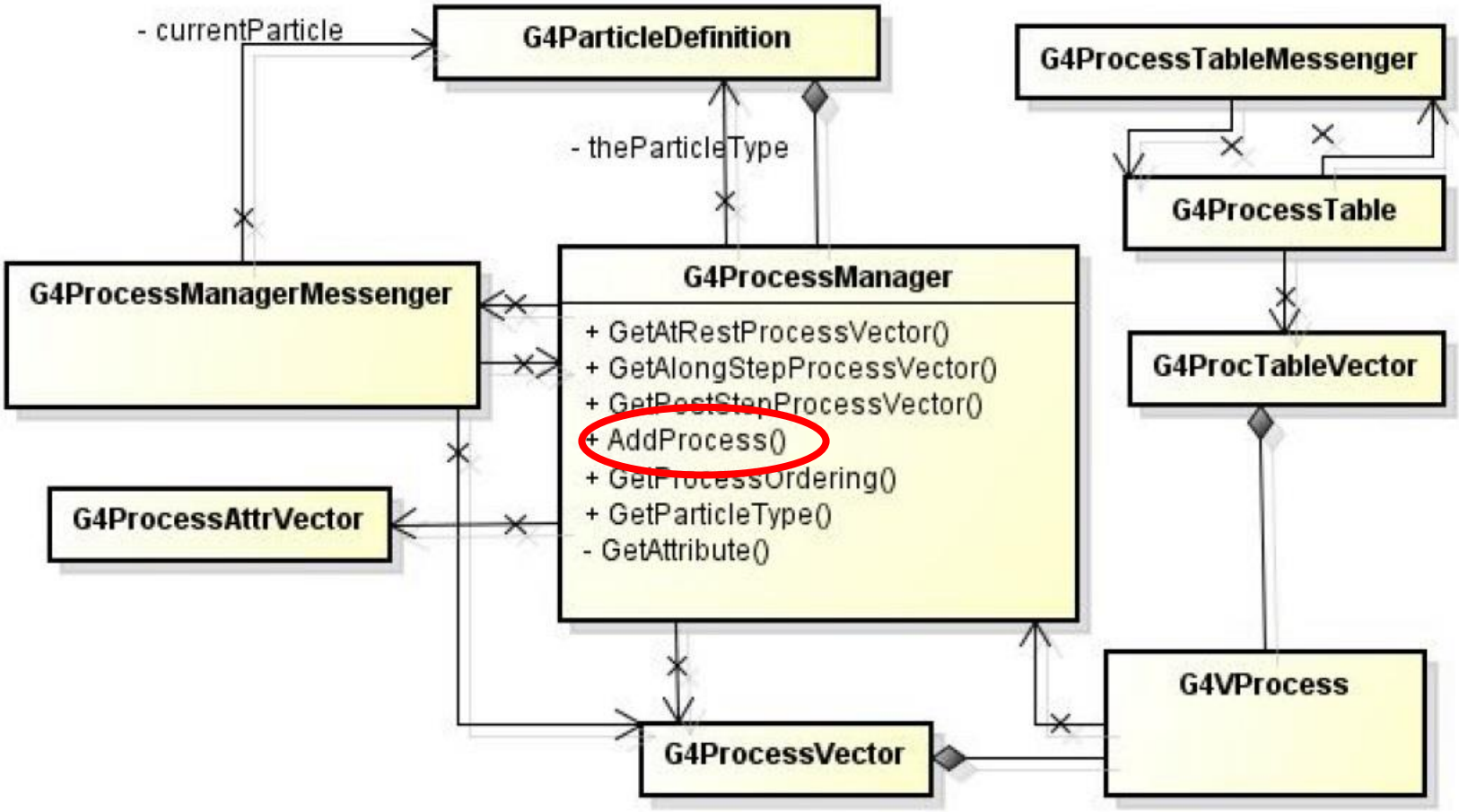


Geant4 particle and processes

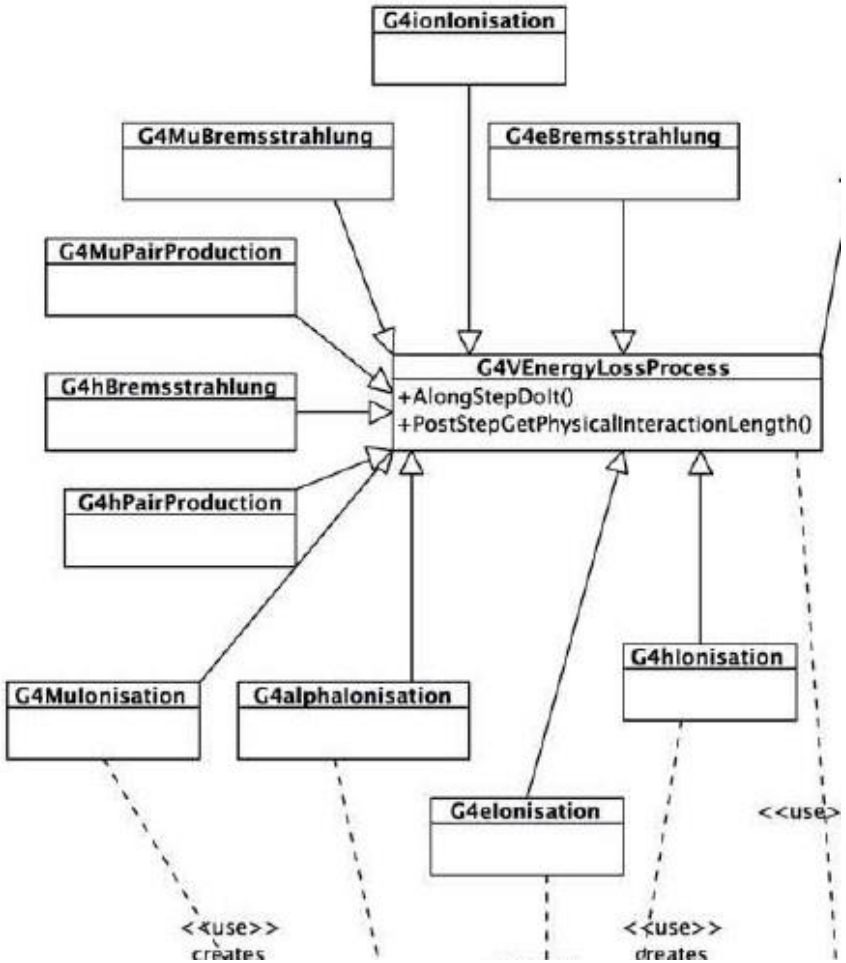
- Particle represented by its own class, which is derived from G4ParticleDefinition
- lepton
- meson
- baryon
- boson
- shortlived
- ion



Geant4 particle and processes



Geant4 models



- Each process described with a model
- Attach own model for dark photon production
- Current implementation is based on muon Bremsstrahlung

Thank You for your attention!