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Energy ranges for air shower simulations with PROPOSAL in C8

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Reminder: Continuous and stochastic electromagnetic interactions

- The bremsstrahlung cross section diverges for small photon energies ω as $d\sigma/d\omega \propto 1/\omega$
- The total bremsstrahlung cross section diverges, while the average energy loss is finite
- To carry out Monte Carlo simulations of this interaction, we have to define an infrared cutoff to the secondary energy, below which we treat energy losses continuously, while all larger losses are treated stochastically
- This cutoff is a small unphysical scale, so we have to choose a value small enough that the simulation results are not influenced by it

Why do we have to talk about energy ranges?

- PROPOSAL uses tables for results of numerical integrations such as the average continuous energy loss and the number of stochastic interactions

$$\left\langle -\frac{dE}{dX} \right\rangle \Big|_{\text{cont}} = \frac{N_{\text{A}}}{A} \sum_{\text{processes}} \int_{\epsilon_{\text{min}}}^{\epsilon_{\text{cut}}} \epsilon \frac{d\sigma}{d\epsilon} d\epsilon,$$

$$\frac{dN}{dX} \Big|_{\text{stoch}} = \frac{N_{\text{A}}}{A} \sum_{\text{processes}} \int_{\epsilon_{\text{cut}}}^{\epsilon_{\text{max}}} \frac{d\sigma}{d\epsilon} d\epsilon,$$

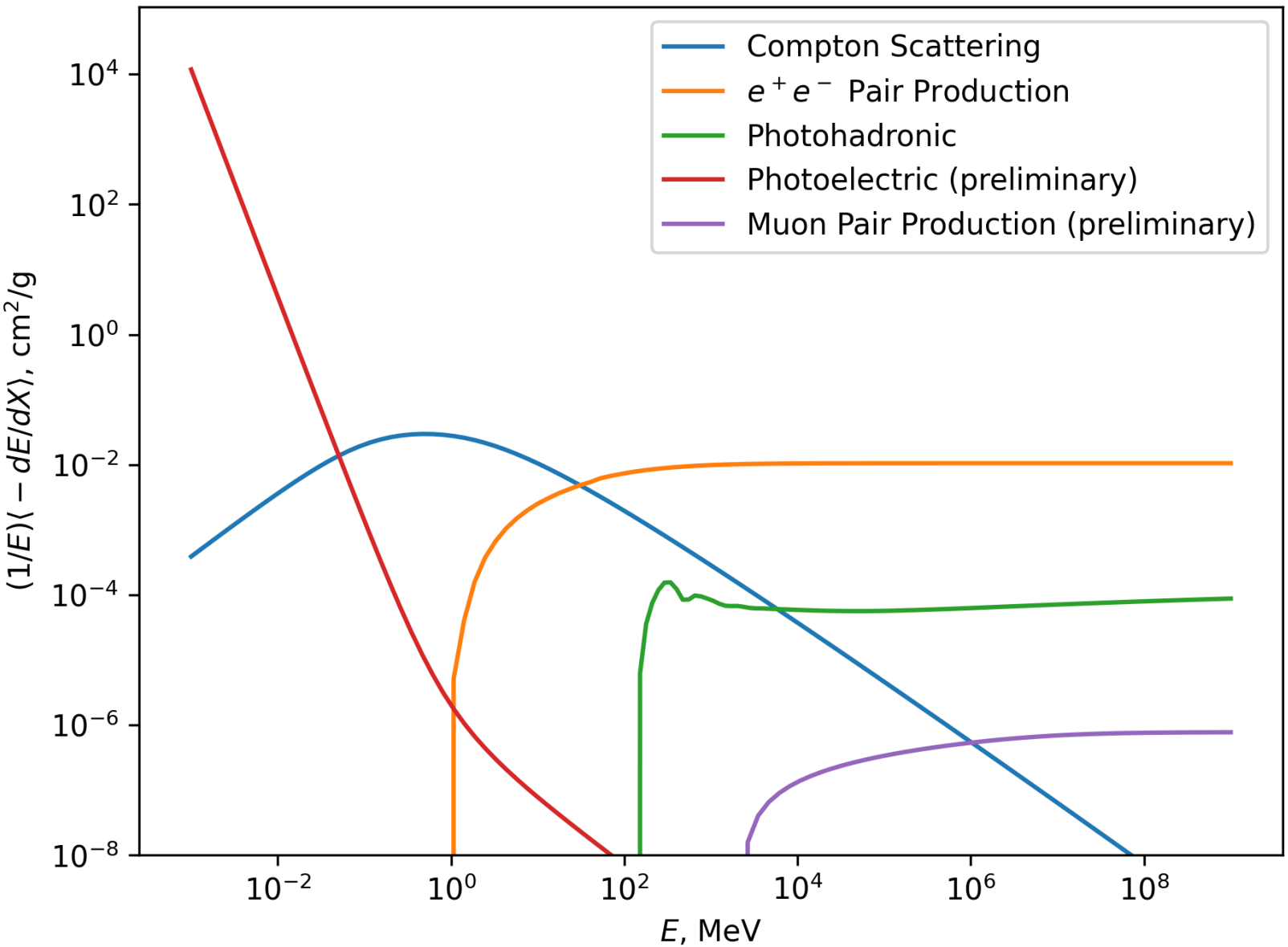
  where $\epsilon = vE$ denotes the energy lost in an interaction.

- NB: Internally, we use the total energy, not the kinetic energy.

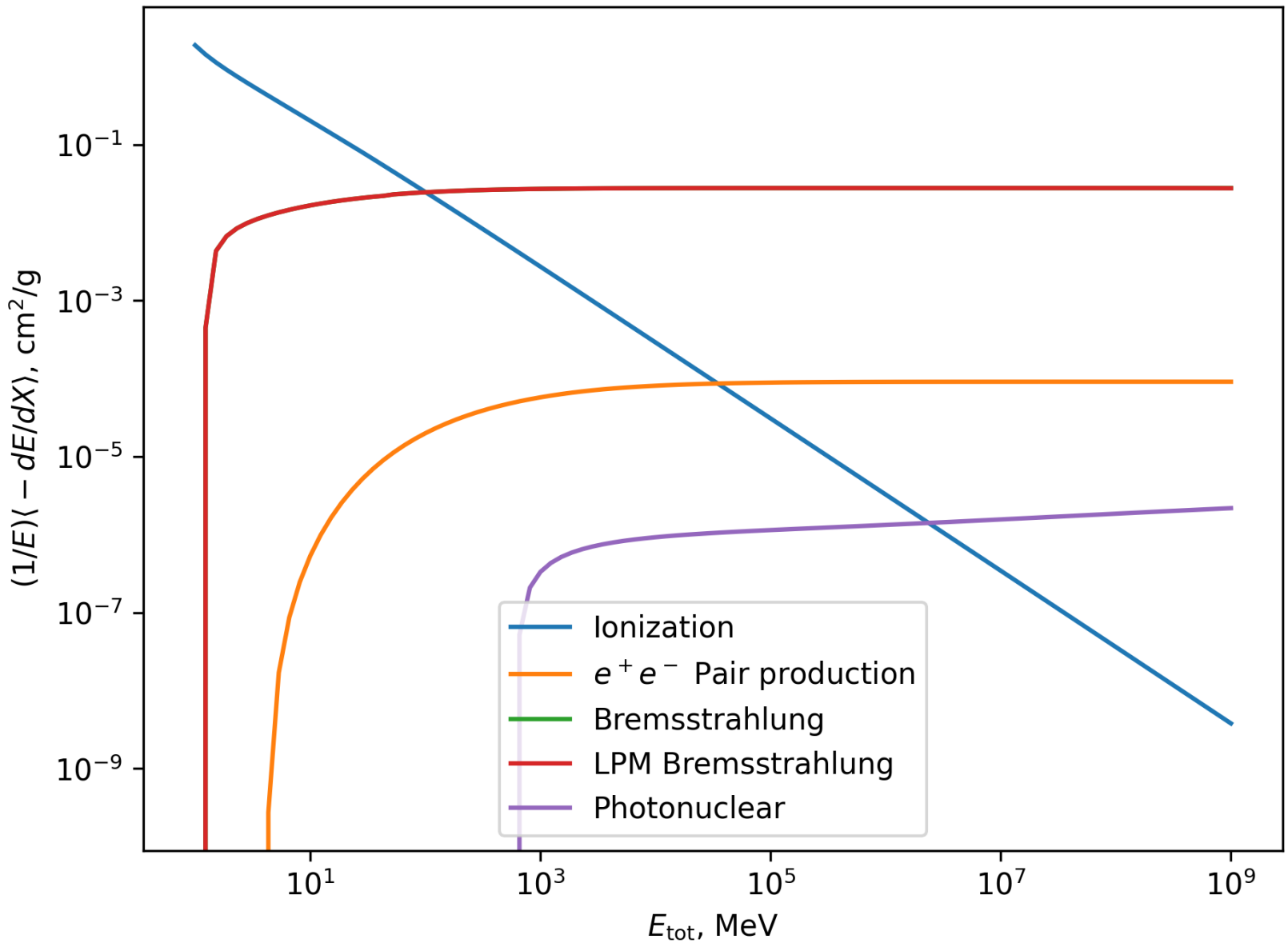
Why do we have to talk about energy ranges?

- We want to avoid extrapolating beyond the boundaries of these tables.
- These tables are generated on startup, if they do not yet exist, or if previously generated tables are for different energy cuts and/or media.
- These tables depend on two energy thresholds, the minimal value of the particle energy E_{min} and the infrared cutoff ϵ_{cut}
- E_{min} is hard-coded; for massive particles, we use the rest mass, for photons we currently use $2m_e$

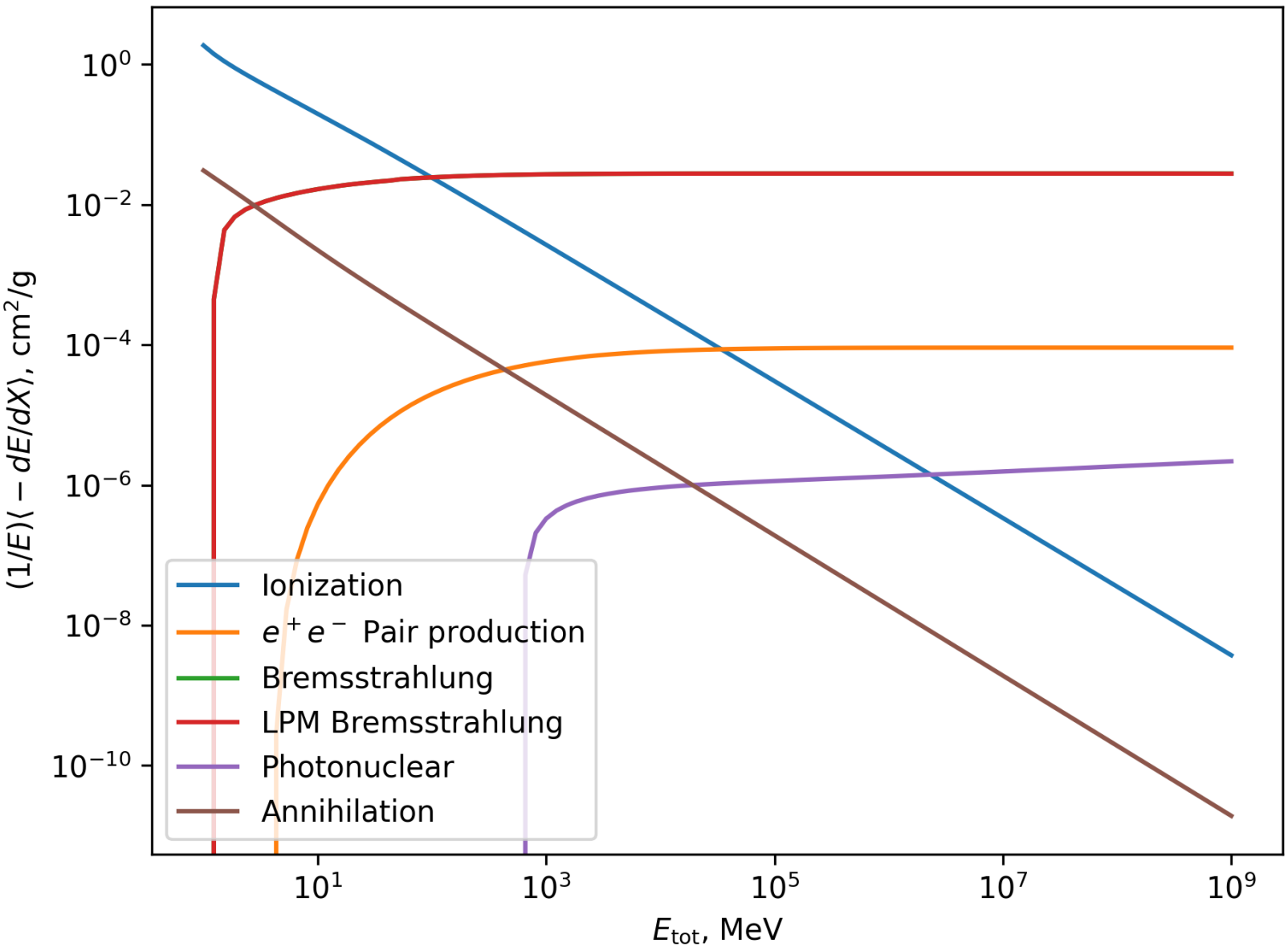
Energy loss of photons in air



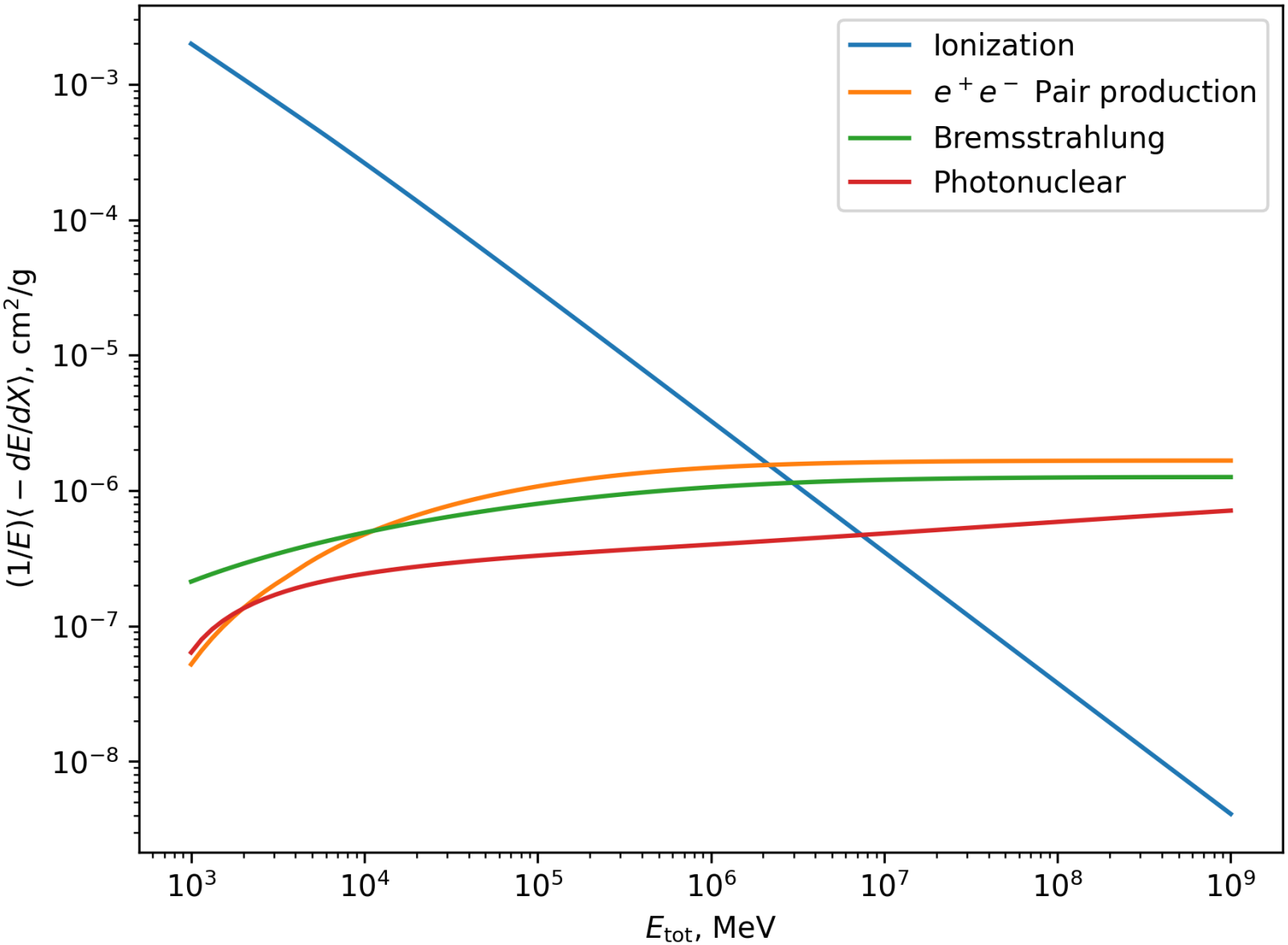
Energy loss of electrons in air



Energy loss of positrons in air



Energy loss of muons in air



Implemented processes in PROPOSAL (for details see Jean-Marco's presentation)

	CORSIKA 7	CORSIKA 8 (ICRC)	CORSIKA 8 (!396)	31.01.2022
Bremsstrahlung	✔	✔	✔	✔
LPM Bremsstrahlung	✔	✘	✘	Concept
LPM e^+e^- pair production ($\gamma N \to e^+e^-N$)	✔	✘	✘	Coming in future
Ionization	✔	✔	✔	✔
e^+e^- Pair Production ($l^\pm N \to l^\pm e^+e^-N$)	✘	✔	✔	✔
Photonuclear ($l^\pm N \to l^\pm X$)	✘	✘	✔	✔
Annihilation ($e^+e^- \to \gamma\gamma$)	✔	✔	✔	✔
e^+e^- Pair Production ($\gamma N \to e^+e^-N$)	✔	✔	✔	✔
$\mu^+\mu^-$ Pair Production ($\gamma N \to \mu^+\mu^-N$)	✔	✘	✘	coming in future
Photohadronic ($\gamma N \to X$)	✔	✘	✘	✔
Photoelectric	✔	✘	✘	Parametrization
Rayleigh Scattering	✔	✘	✘	✘
Compton Scattering	✔	✔	✔	✔
Multiple Scattering	✔	✔	✔	✔
Bremsstrahlung Deflection	✔	✘	✔	✔
Ionization deflection	✔	✘	✔	✔
e^+e^- Pair production ($l^\pm N \to l^\pm e^+e^-N$) deflection	✘	✘	✘	only muons
Photonuclear deflection ($l^\pm N \to l^\pm X$)	✘	✘	✘	only muons
Fluorescence	✔	✘	✘	✘

Consequences

- Photoelectric effect is not implemented yet $\Rightarrow$ too few low-energy electrons
- Photonuclear interactions $\ell N \to \ell X$ and photohadronic interactions $\gamma N \to X$ are implemented, but C8 cannot (yet) handle these interactions $\Rightarrow$ too few muons, presumably some effect on angular/lateral distribution
- Muon pair production by photons $\gamma A \to \mu^+ \mu^- A$ is currently missing $\Rightarrow$ too few muons in EM-showers

Discussion: What energy ranges are important for CORSIKA 8?

- Which energy ranges contribute to the air shower observables your are interested in?
- What are the highest and lowest energies you need to consider?
- How small are the energy losses of propagating particles you need to consider?
- All this is in principle configurable, but if we need for example very low energies, we might need to add processes we neglected so far