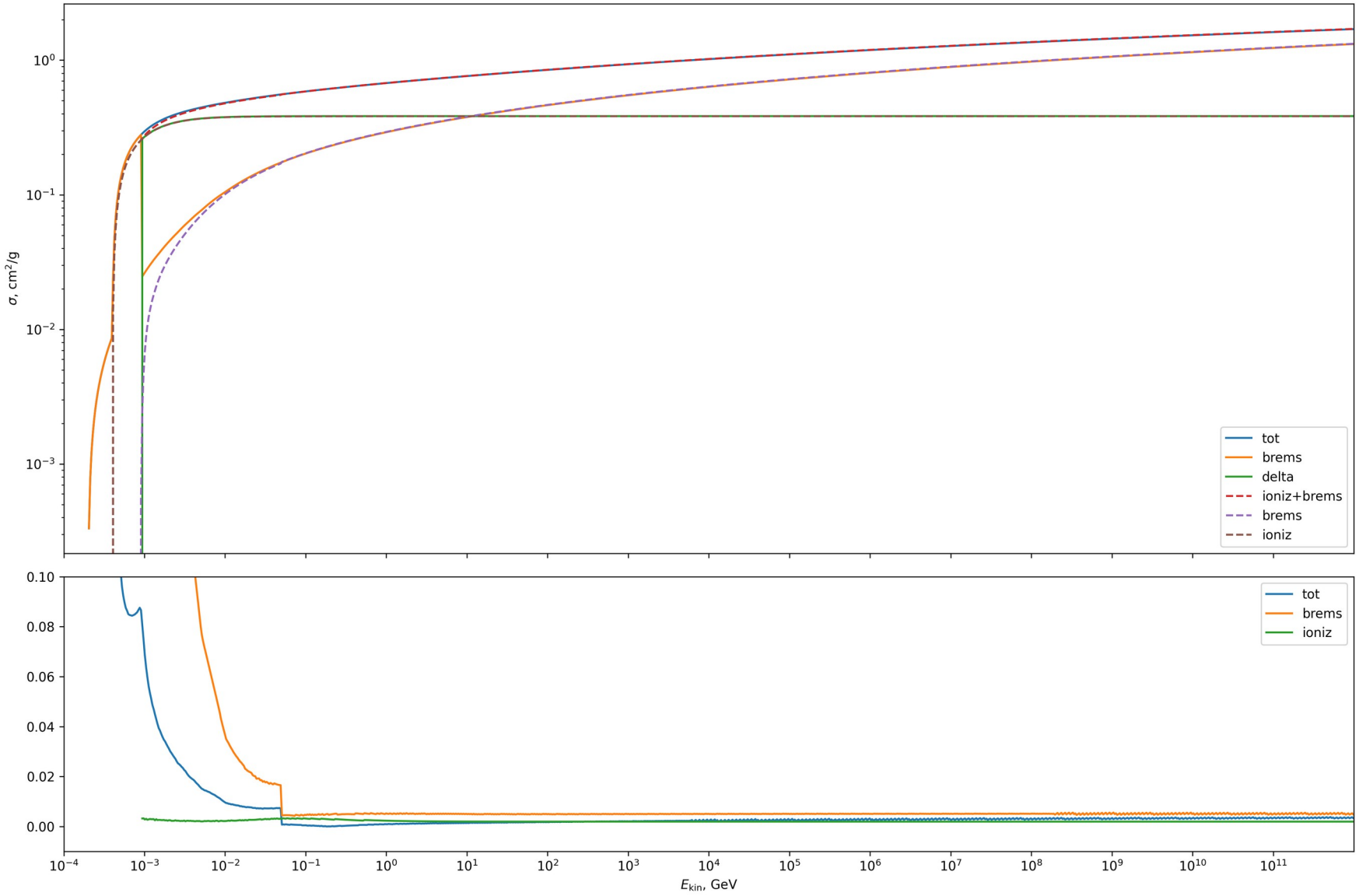
Electromagnetic interaction cross-section comparison between PROPOSAL and modified EGS4 in C7 or CONEX

EGS cross sections

- Tanguy gave us cross-section tables he extracted from C7 for CONEX together with the cuts used (e_{cut} = 200 keV).
- This enables us to make a direct comparison between the cross-sections in C7 and C8.
- In the following plots, solid lines are C7/CONEX/modified EGS4, dashed lines are PROPOSAL 7.3.1, commit 4451c2ee103beee2d15606e09be2fccfd28afaa8 (Fr, Aug 5, 2022).

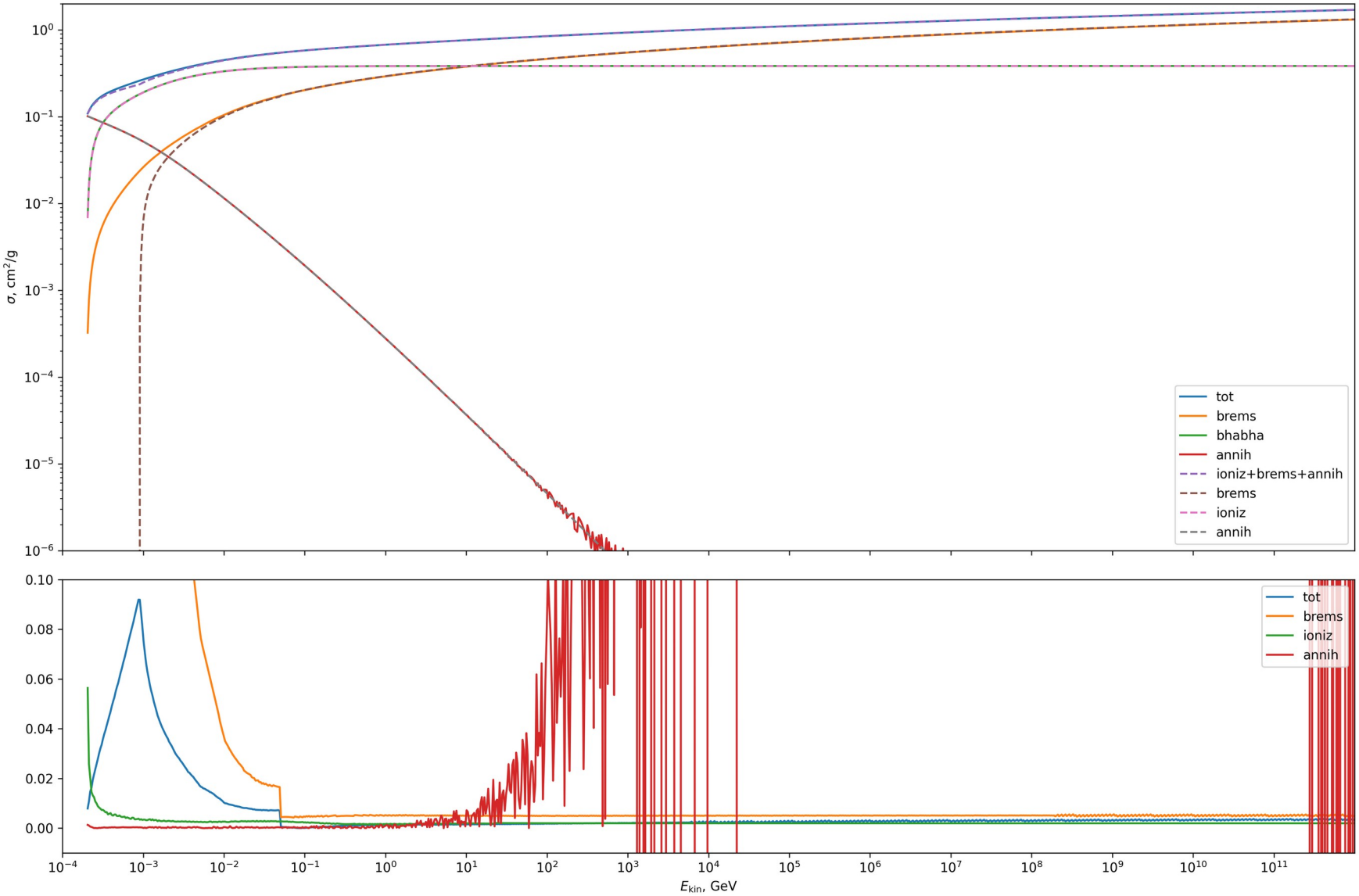
Electron cross-sections in PROPOSAL 7.3.1



Electron cross-sections in PROPOSAL 7.3.1

- Below $E_{kin} \sim 0.9$ MeV, bremsstrahlung and ionisation are added together in EGS 4, therefore one has to compare the total stochastic cross-section.
- There is a jump in the ratio at 50 MeV; this is not unexpected, because there is an empirical correction factor from tables by Koch & Motz to the high-energy cross-sections.
- Unmodified PROPOSAL shows differences of about 5×10^{-4} at high energies for the total cross section, 1–5% between 1.2 and 50 MeV, rising to about 9% at 1 MeV.

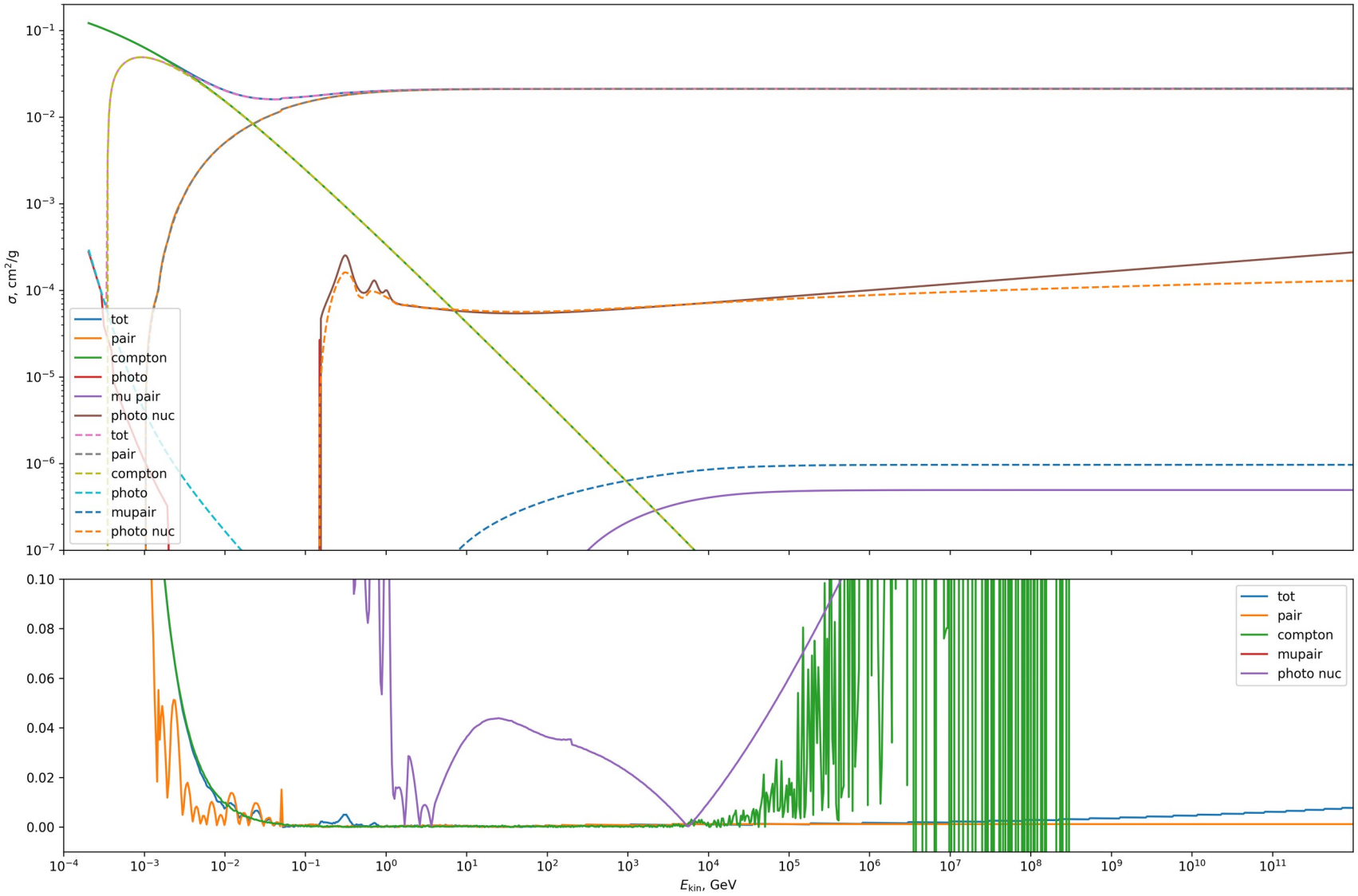
Positron cross-sections in PROPOSAL 7.3.1



Positron cross-sections in PROPOSAL 7.3.1

- Similar to electrons, the total cross-section has to be compared.
- The differences amount to -5×10^{-4} at high energies, jumping to about 0.8% below 50 MeV increasing to a maximum deviation of about 9% around 1 MeV.
- Annihilation has practically no deviation outside the region of numerical almost-zero fluctuations

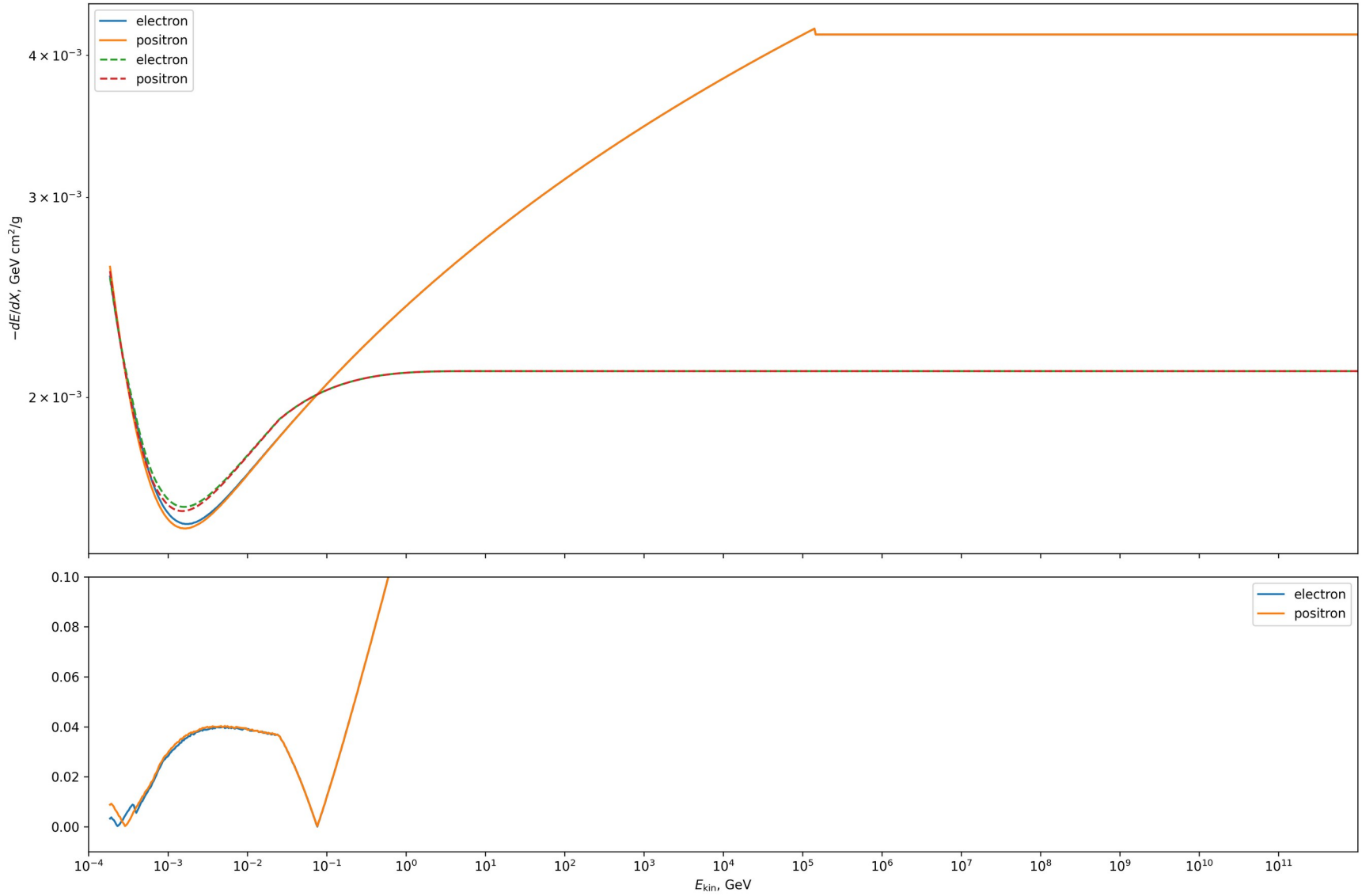
Photon cross-sections in PROPOSAL 7.3.1



Photon cross-sections in PROPOSAL 7.3.1

- Compton scattering is continuous below e_{cut} in PROPOSAL, while photon propagation is completely stochastic in EGS 4.
- The photoelectric effect shows considerable differences, but gives only a very small contribution.
- The total cross section differs at very high energies due to different photohadronic cross sections (~ln s [Caldwell et al.] vs. ~$s^{0.08}$ [Breitweg et al. (ZEUS)]).
- At energies down to about 1 MeV, the total deviations are smaller than 1%.
- The differences at small energies are due to Compton scattering (partly continuous vs. totally stochastic)
- Muon photoproduction differs considerably!

Continuous losses in PROPOSAL 7.3.1



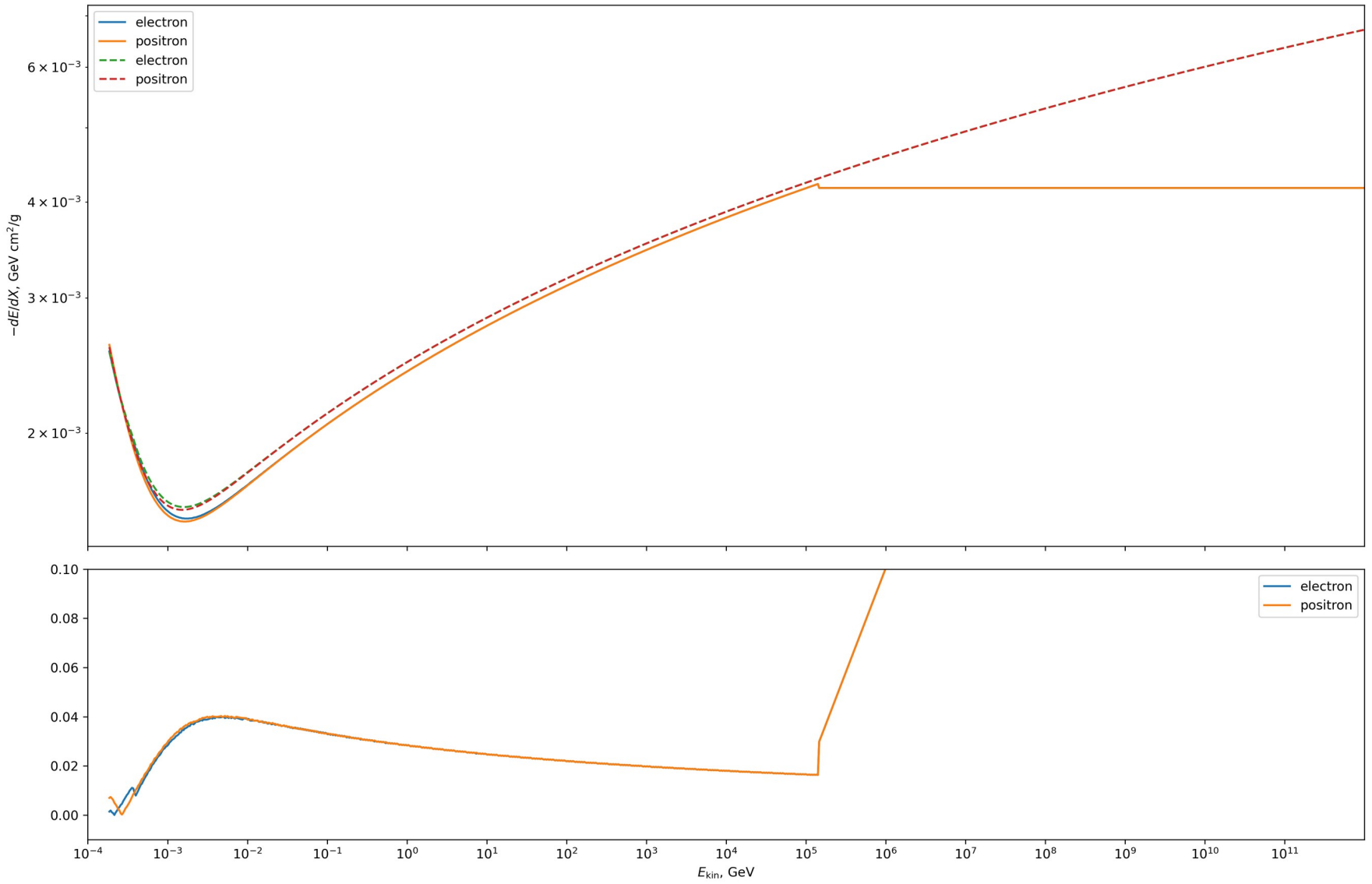
Continuous losses in PROPOSAL 7.3.1

- Continuous losses of electrons and positrons show a similar qualitative behaviour, but differ by a factor ~2.
- This is mostly due to the (negative) density correction to the ionisation loss included in PROPOSAL.
  - Since this is clearly density dependent, we should actually have the same problems as with the LPM-effect in inhomogeneous media to correctly use the local density.
  - The density used here for air is the standard density for air at sea-level pressure.

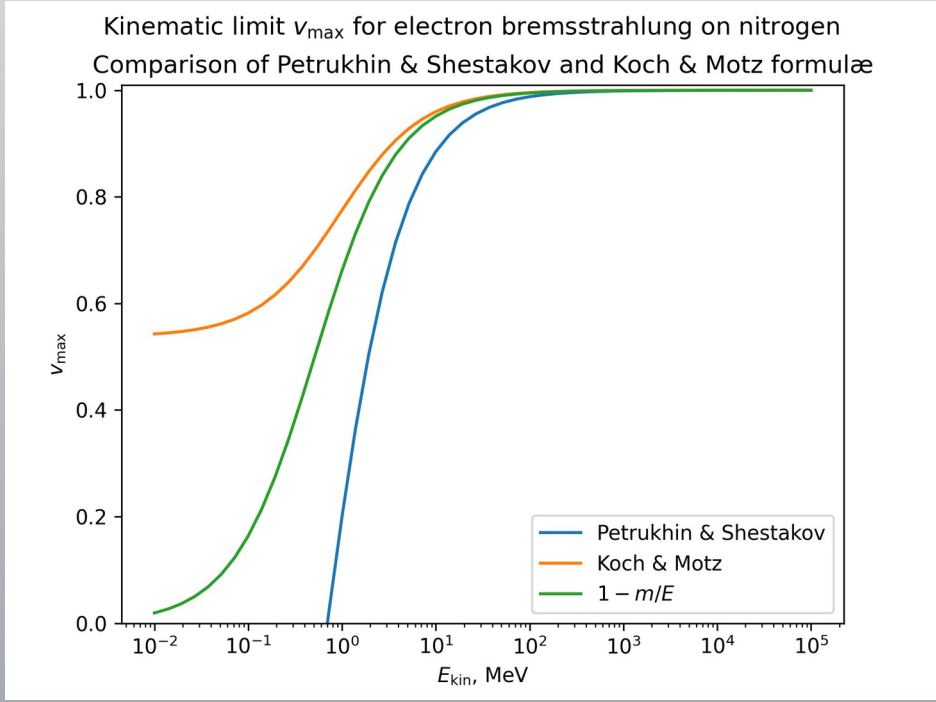
Reasons for differences and comparison with modified PROPOSAL

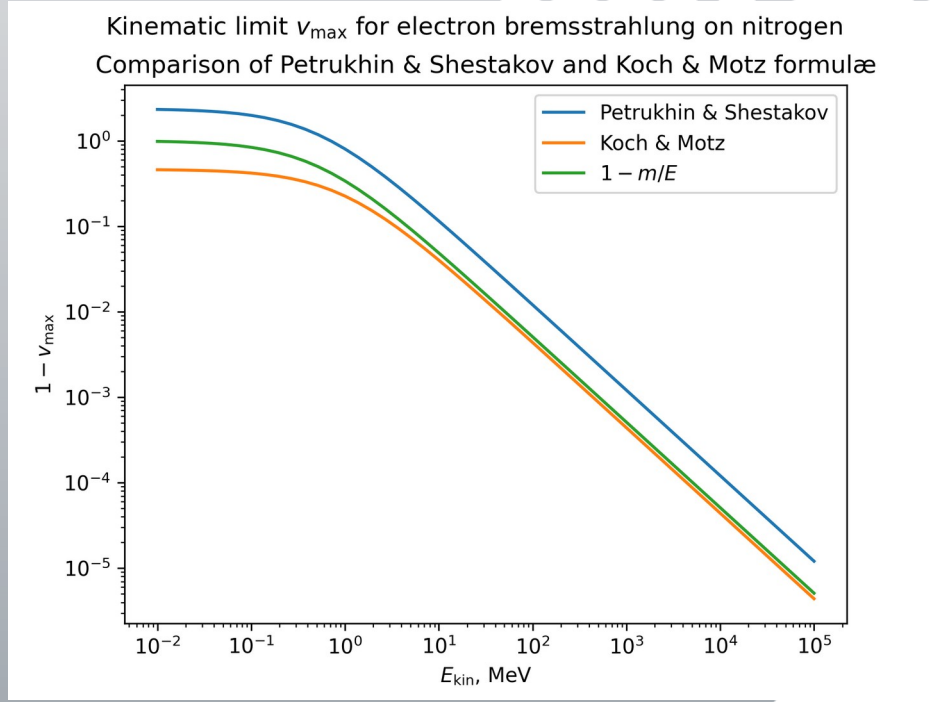
- Continuous losses
  - Difference falls to about 2–4% if the density correction δ is set to zero.
  - Correct usage of the local density is difficult, because δ is a nonlinear function of the density.
- Electron & positron bremsstrahlung
  - The maximum bremsstrahlung loss v_{max} is taken in PROPOSAL from a paper by Petrukhin & Shestakov (1966) on muon bremsstrahlung (with the current lepton mass) by setting the screening function Φ to zero.
  - EGS 4 determines the maximum value by setting their expression for the screening functions to zero.
  - The differences fall to about 2–3% with these limits.
  - NB: this v_{max} is larger than 1 – m/E, which should be the absolute upper limit. The agreement is better with 1 – m/E.
- This has been temporarily changed with the PROPOSAL branch `no_density_effect_ionization`

Continuous losses without density correction δ

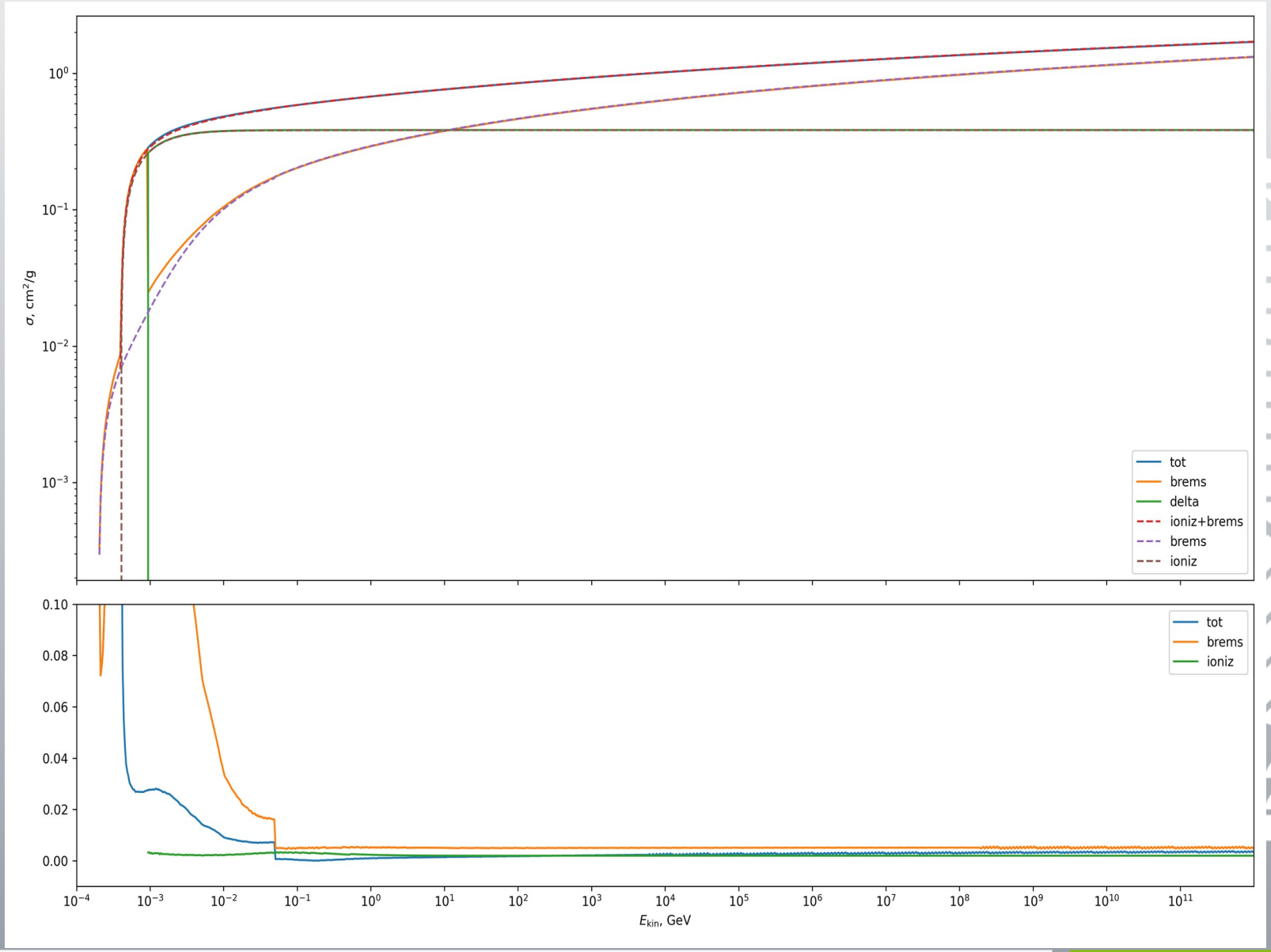


Comparisons of the different prescriptions for the bremsstrahlung kinematic limits

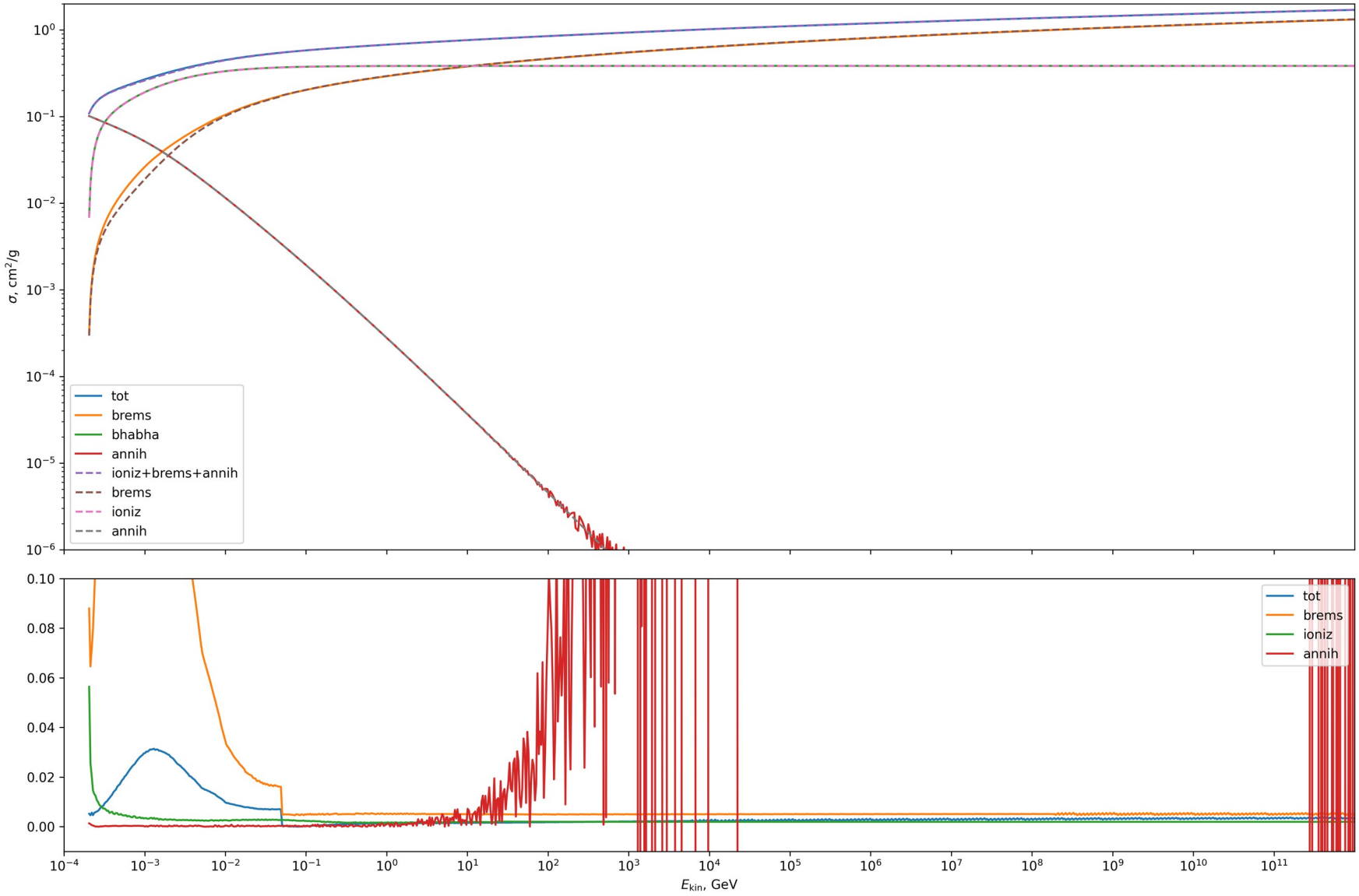




Electron losses with limit $v_{max} = 1 - m/E$ (PROPOSAL:brems_koch_motz)

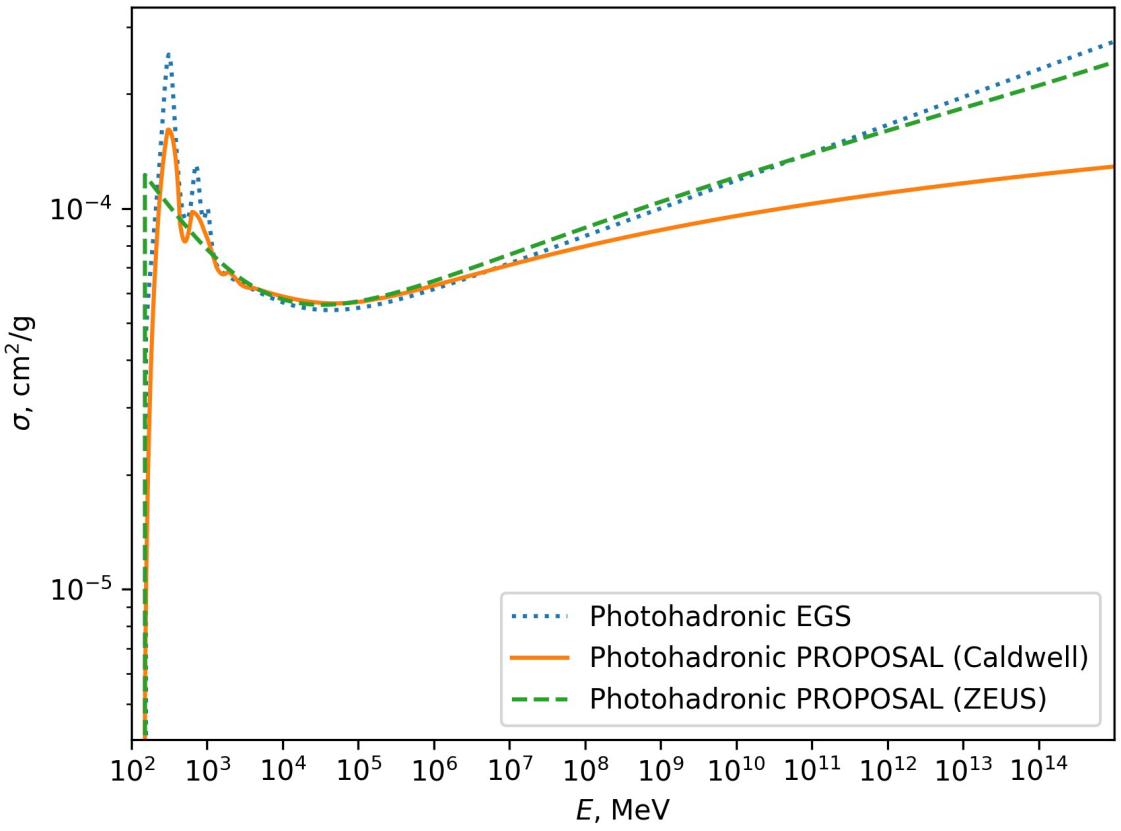


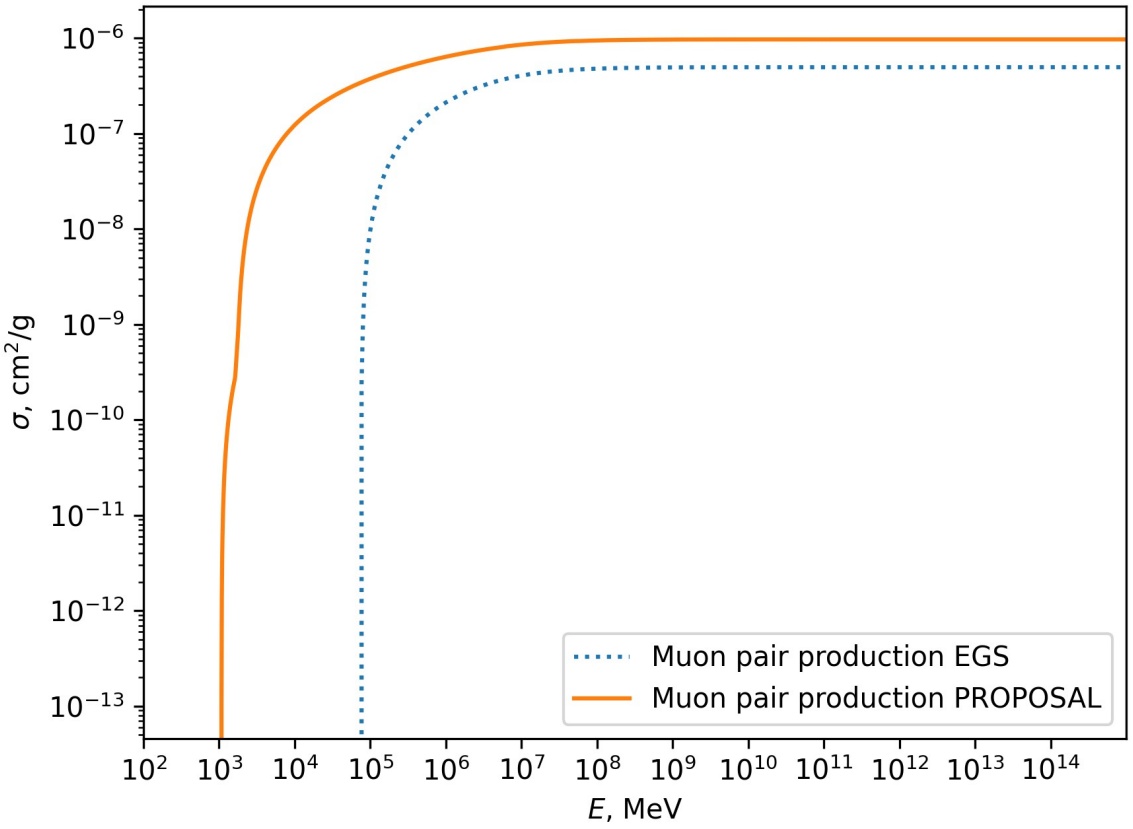
Positron losses with limit $v_{max} = 1 - m/E$ (PROPOSAL:brems_koch_motz)



Conclusions

- We found significant differences of the cross-sections, in particular at lower energies.
- We have gotten rid of most of these differences for electrons/positrons
  - The differences amount to no more than ~3% in the total stochastic cross section
  - Effect on air showers remains to be investigated
- There are several differences for photons
  - Some we do understand
    - Photohadronic interaction uses a different parametrization
    - Compton scattering is partly continuous in PROPOSAL, so there should be no overall effect of dividing up the cross-section
  - Some we do not understand
    - Why is muon pair production starting at a significantly higher energy in CONEX?


10^{-4}
10^{-5}
σ, cm^2/g
10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14}
E, MeV
Photohadronic EGS
Photohadronic PROPOSAL (Caldwell)
Photohadronic PROPOSAL (ZEUS)


10^{-6}
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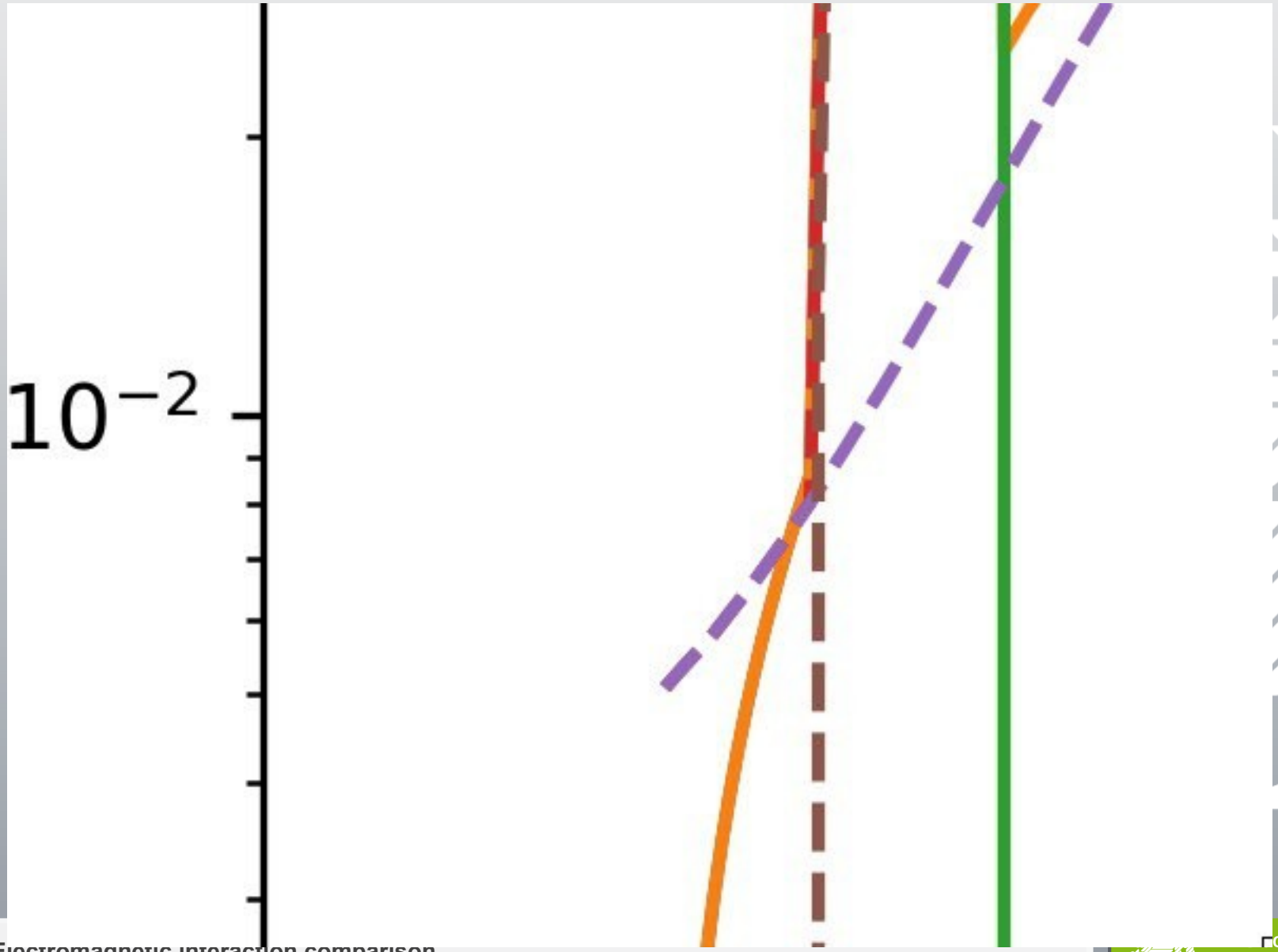
σ, cm²/g
10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14}
E, MeV
Muon pair production EGS
Muon pair production PROPOSAL


10^{-2}