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Corrections to the pair production by high energy muons

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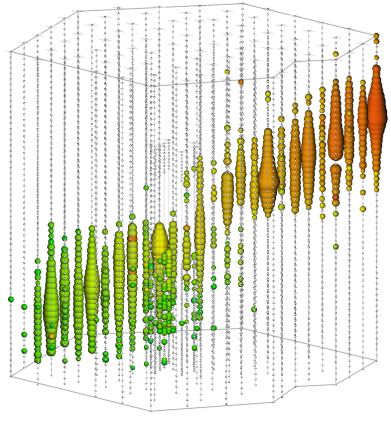
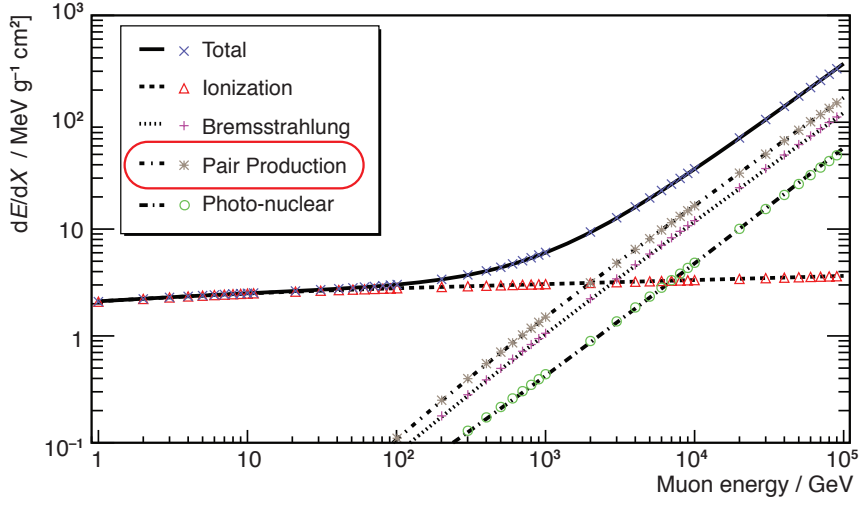
Motivation

- Energy reconstruction for tracks depends on knowledge of energy losses
- Calculation of energy losses by simulations (PROPOSAL, GEANT4)
- Reduce systematic uncertainties in simulations
- Calculate muon cross sections with higher accuracy

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = a + b(E)E$$



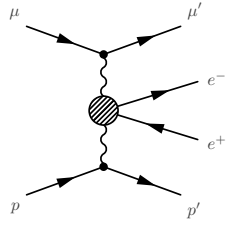
Energy losses



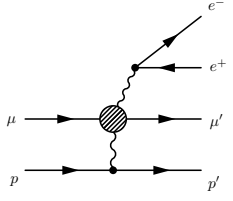
J.H. Köhne: PhD Thesis, 2013

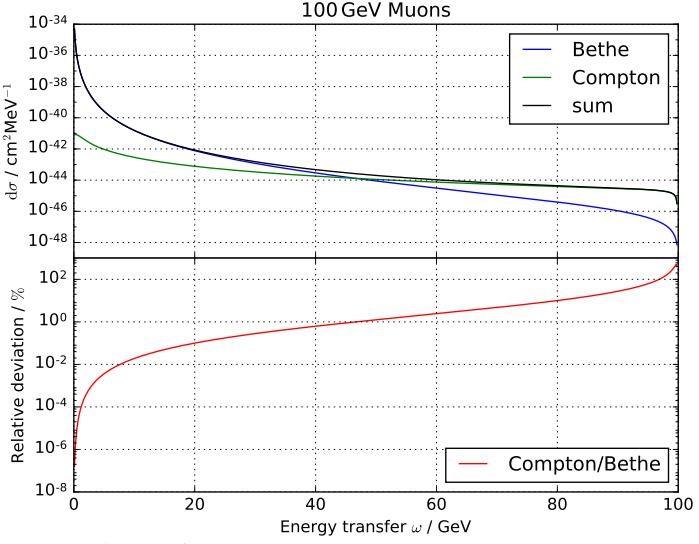
Pair production: Diagrams

Bethe-Heitler process



Compton process





Pair production: PROPOSAL

Parametrization by Kelner-Kokoulin-Petrukhin (1971)

- Relativistic approximation ($\frac{m^2}{E^2} \ll 1$)
- Form factor:
  - Nuclear: Fermi charge-density distribution
  - Atomic: Thomas-Fermi model for screening effects
- Atomic electrons (1998)
- Muon production (2000)

Possible improvements

Uncertainties arise from:

- Relativistic approximation
- Target atom interaction

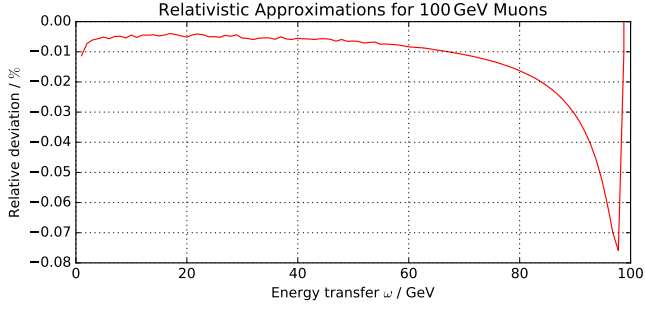
Perturbative expansions

- Radiative corrections: radiation field $\mathcal{O}(\alpha)$
- Coulomb corrections: nuclear field $\mathcal{O}(Z\alpha)$

Pertubative expansions: Approach

- Parametrization by Bugaev without kinematic approximation

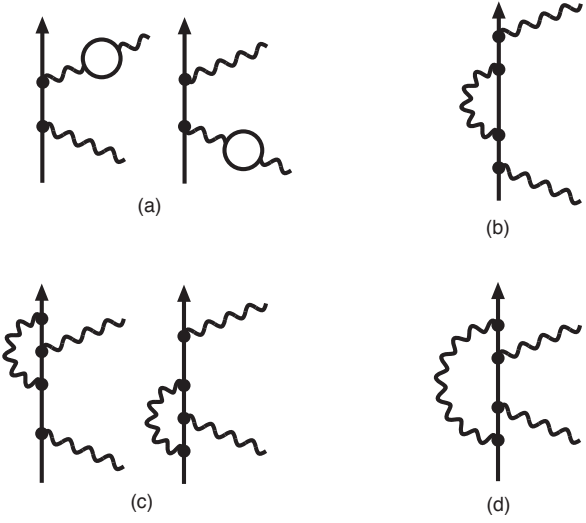
$$\frac{\frac{\mathrm{d}\sigma_{\text{approximation}}}{\mathrm{d}\omega}}{\frac{\mathrm{d}\sigma_{\text{exact}}}{\mathrm{d}\omega}}$$



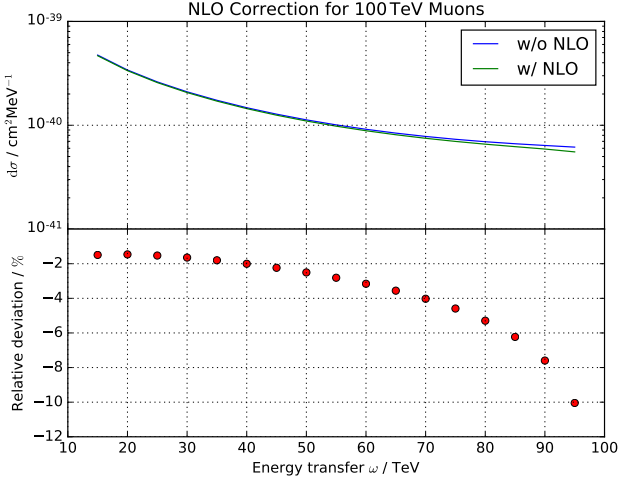
Pertubative expansions: Radiative corrections

Next-to-Leading Order (NLO)

- One loop corrections
  - Vacuum polarization (a)
  - Self energy (b)
  - Vertex correction (c)
  - Box graph (d)
- Emission of additional bremsstrahlung photon



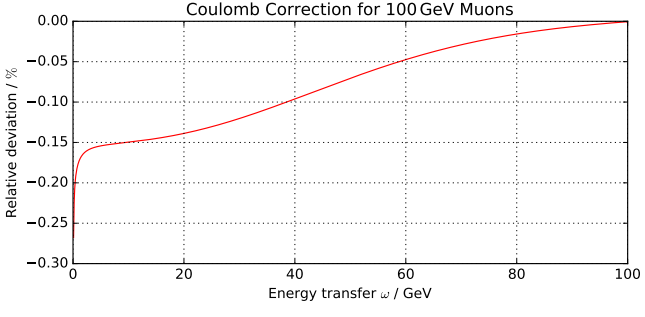
Pertubative expansions: Bremsstrahlung (preliminary)

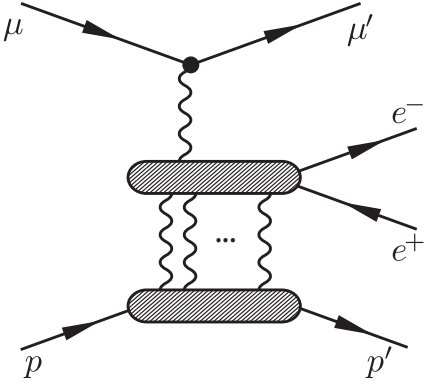


Alexander Sandrock

Pertubative expansions: Coulomb corrections

- $Z\alpha$ is not small for heavy nuclei $\Rightarrow$ non-perturbative QED
- Ivanov (1998)
  - Recurrence relations to sum Feynman diagrams
  - Coulomb field $\rightarrow$ Effect of form factors?





Conclusion

Summary

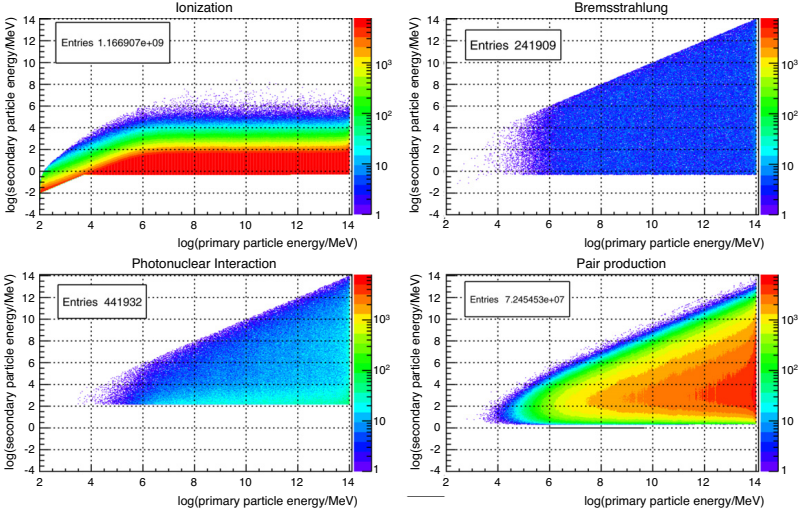
- Consider all uncertainties and processes
- Bremsstrahlung: first results indicate a percent effect in NLO corrections

Outlook

- Pair production NLO processes
- Coulomb correction with form factors
- Interpolation and Implementation in PROPOSAL

Backup slides

Stochastic energy losses



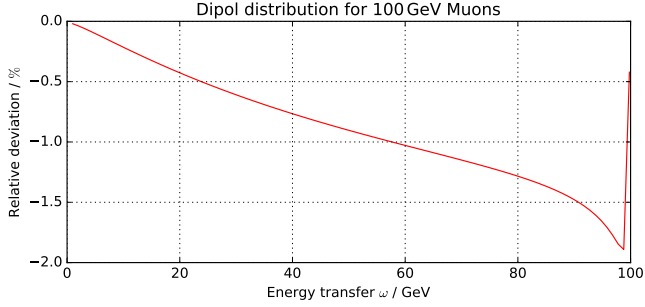
Interaction with target atoms

Simple assumption

- Pointlike nucleus
- Pure Coulombfield

Form factor

- Atomic: screening
- Nuclear: charge-density
- Elasticity

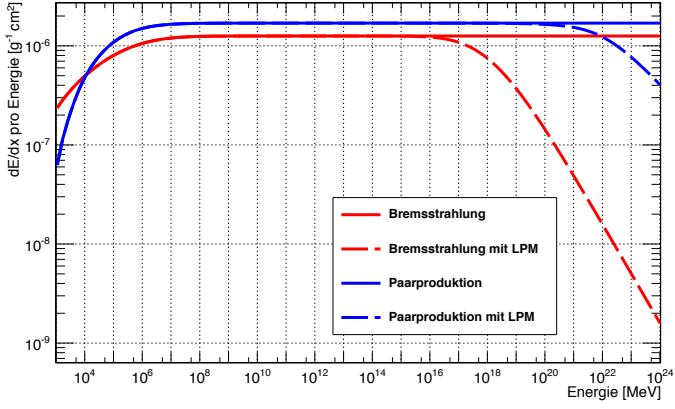


Numerical integration

- One-dimensional: QUADPACK
  possible to handle integrable singularities
- Multidimensional: DCUHRE
  deterministic integration

LPM Effect

Higher energies → greater coherence length → multi-scattering



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