technische universität dortmund

SFB 876 Providing Information by Resource-Constrained Data Analysis

DFG

e5 experimentelle physik 5
astroteilchenphysik

Feasibility study to measure the muon bremsstrahlung cross section with the energy loss profile using neutrino telescopes

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Muon Cross Section Uncertainties

- Muon cross sections are known to the percent level
  - What effects do small changes of the cross section have?
  - Are these effects measurable?
  - Should the uncertainties be included in the systematics?

Recent developments about uncertainties were shown by Alexander Sandrock this morning.

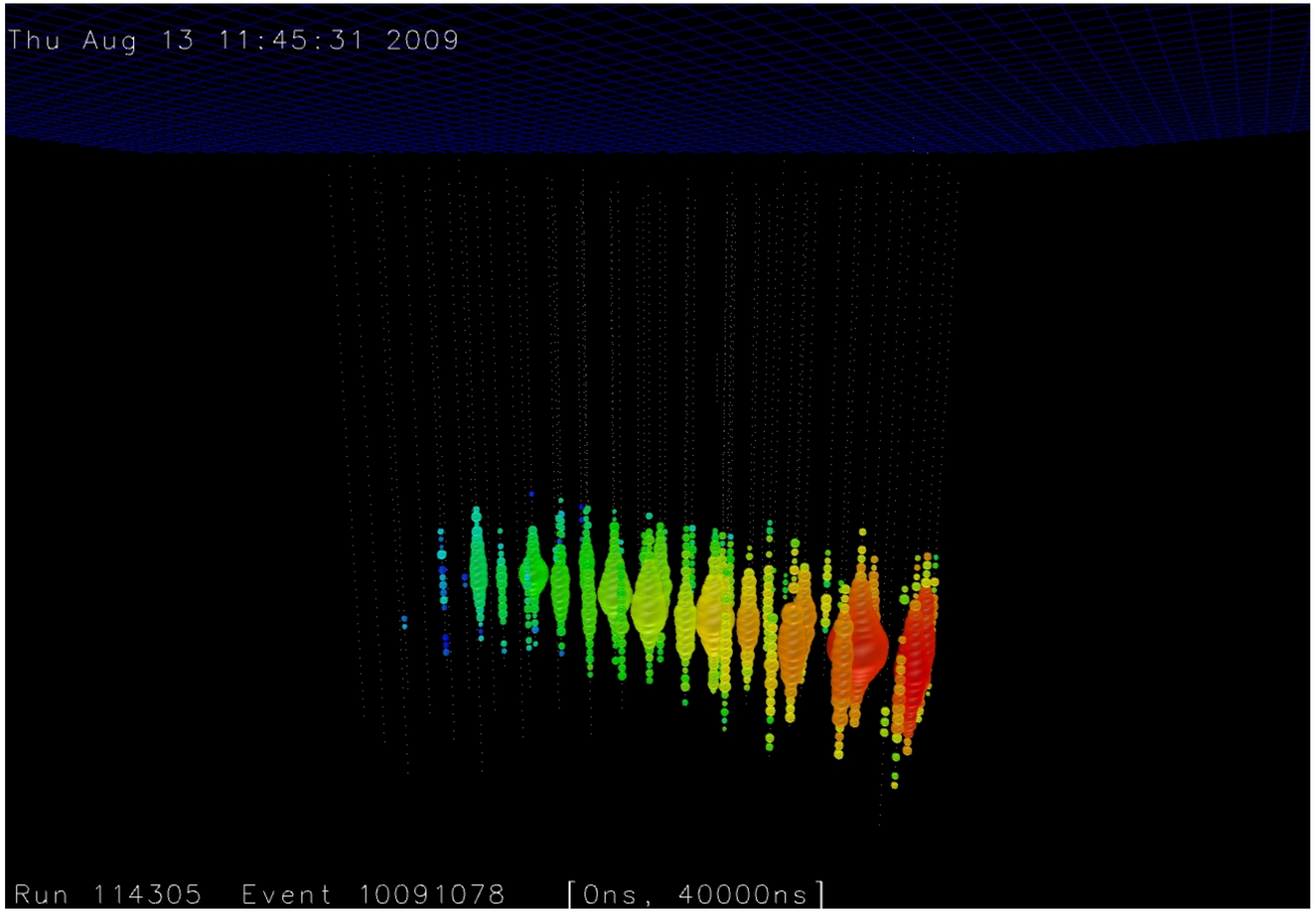
Process, value, parameter	Uncertainty of: 1991	1997
Theoretical		
Extrapolation of $\sigma_{\gamma N}$ (ω)	2%	1%
Bremsstrahlung and pair production on atomic electrons	2.5%	<1%
Nuclear size correction for muon bremsstrahlung	3%	<1%
Fluctuations of energy loss due to pair production	2%	<1%
(A,Q^2) - dependence of photonuclear muon interaction	-	1-2%
Radiative corrections to pair production, bremsstrahlung, photonuclear interaction	-	1-2%
Atomic formfactor accuracy	-	1-2%
Experimental		
Estimation of rock thickness:		
- flat surface	1-2%	1-2%
- mountain overburden	2-5%	2-5%
Rock composition (Z^2/A)	1-2%	1-2%
Total theoretical	~5%	2-4%
Total experimental	2-5%	2-5%
Grand total	5-7%	3-7%

Kokoulin, Nucl Phys B70 (1999) 475

Neutrino Telescopes as Muon Detectors

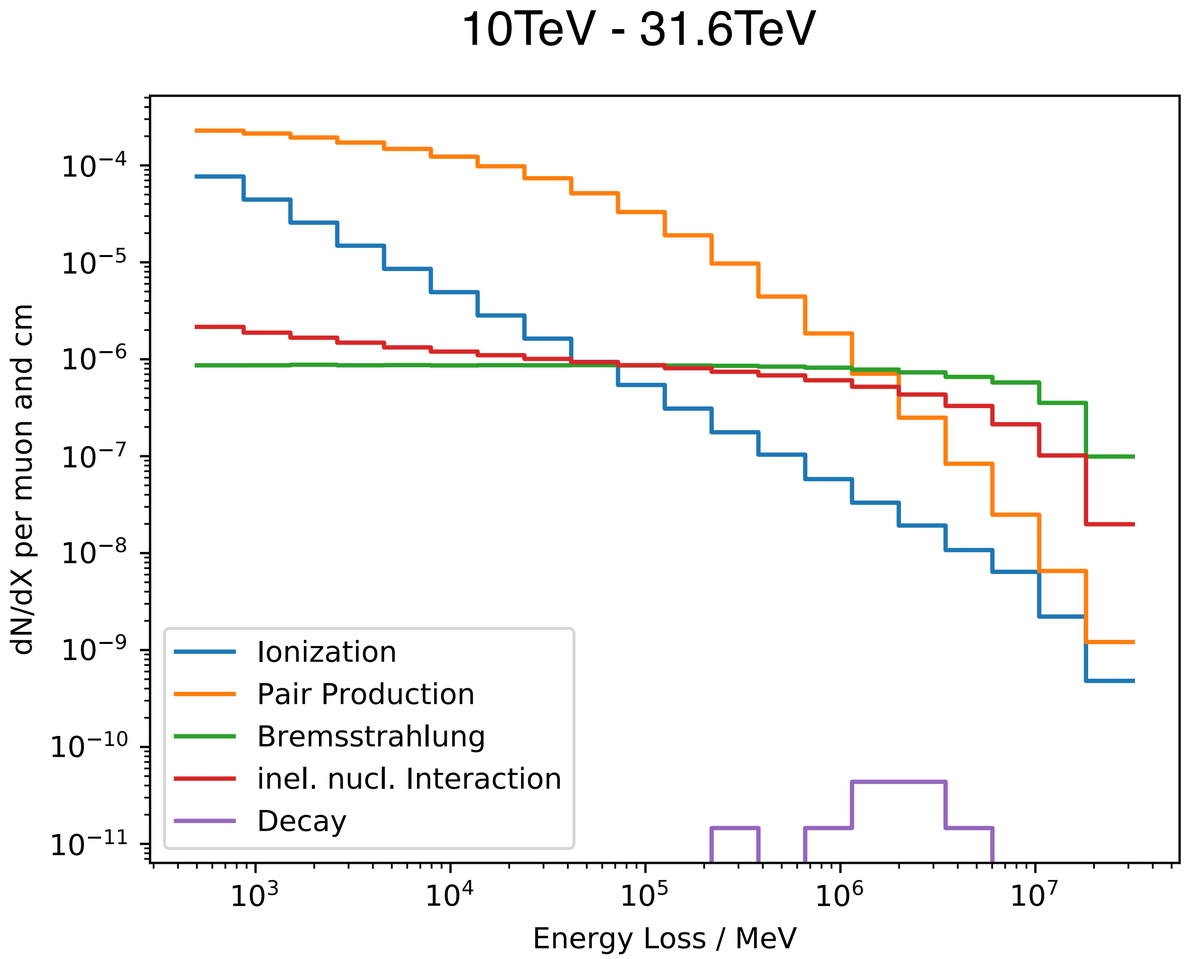
- Searches for rare events
  - Glashow Resonance, ν_τ
  - Depend on precise descriptions of stochastic processes of muons as main background

- IceCube, Baikal-GVD, KM3Net, P-ONE
  - Cubic kilometer scaled detector
  - Long muon tracks inside the detector
  - Energy loss profile of high energy muons



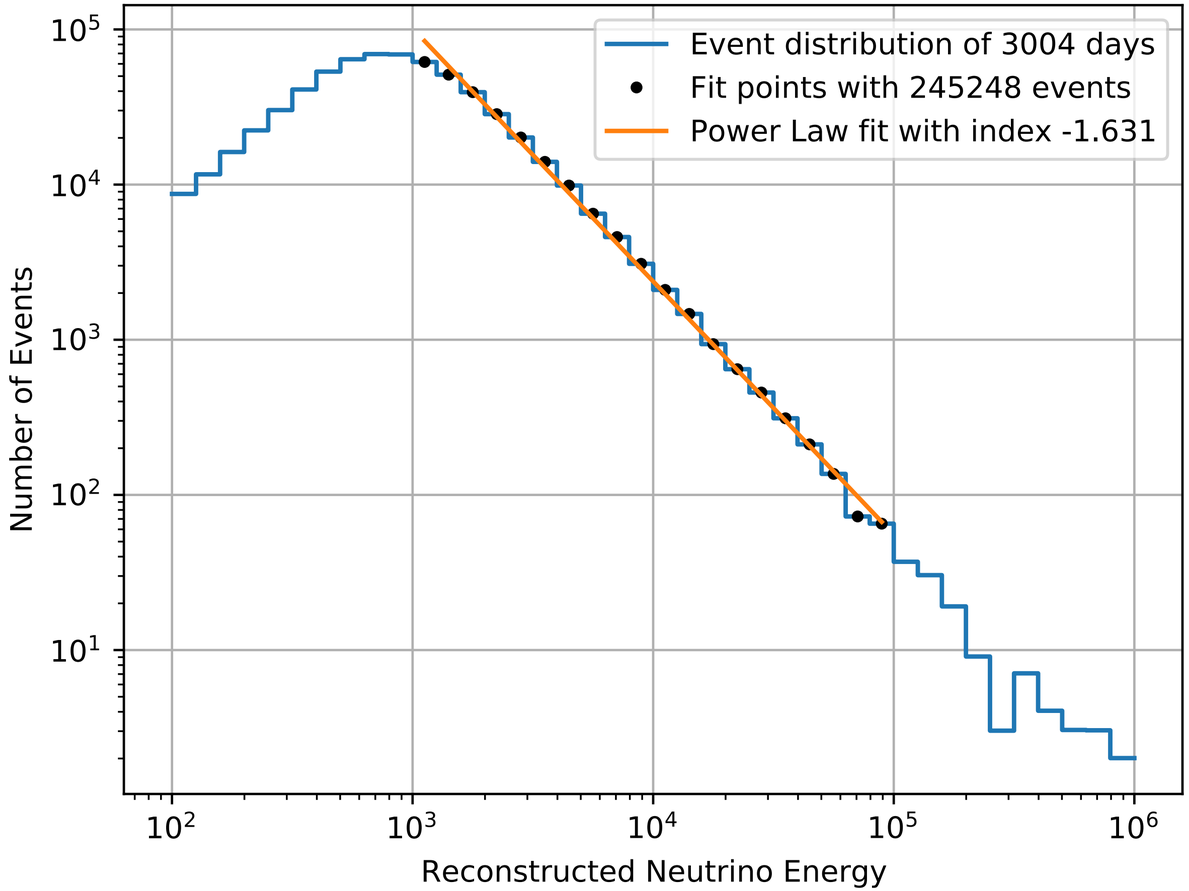
Idea of Bremsstrahlung Cross Section Measurement

- Produce Simulation datasets differing in the scaling of the Bremsstrahlung (Multiplier)
- Reconstruct energy losses, propagation length and energy for different resolution settings
- Create 5 energy loss distributions for the muon energy intervals [1, 2.15, 4.64, 10, 31.6, 100] TeV
- Interpolate the differences of the energy loss bins between the Multiplier
- Estimate the performance on a test set



Single Muon Sample

- IceCube northern track sample of the diffuse ν_μ analysis
  - Mainly through-going Muons
  - Starting events with additional hadronic cascade can be neglected
  - Almost 10 Years of Data
  - Roughly 245.000 events

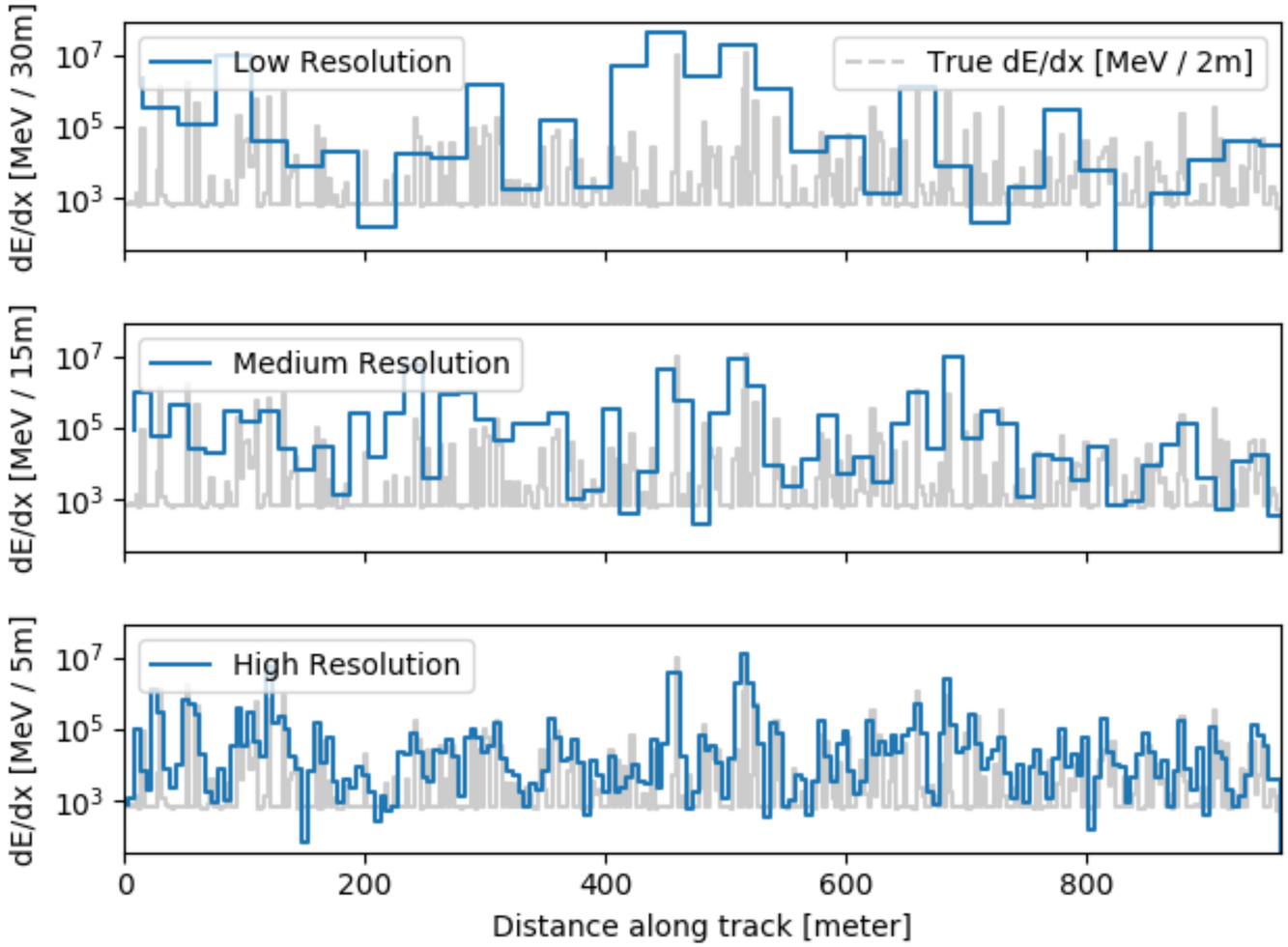


Data taken from Stettner PoS(ICRC2019) 1017

Simulation and Reconstruction

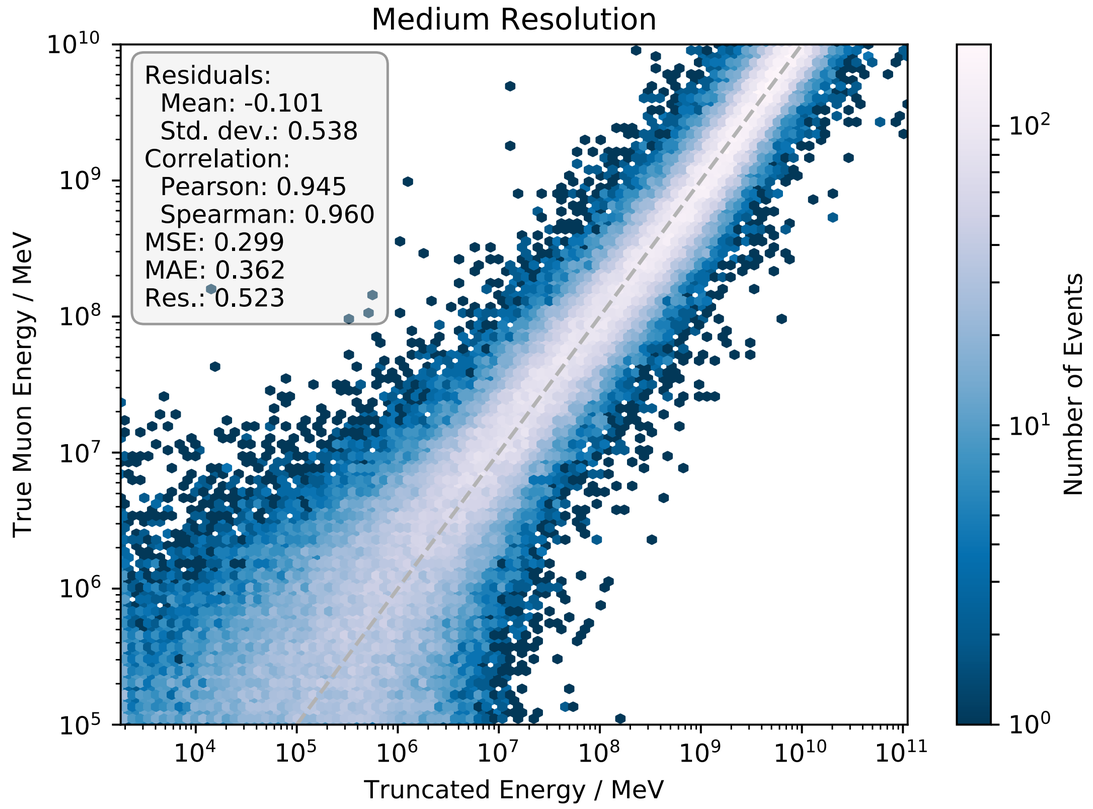
- Muon Propagation with PROPOSAL (see talk by Jean-Marco Alameddine on Friday)
  - Energy loss cut of 500MeV
  - Energy spectrum E^{-1}
  - Energy range [100GeV, 1PeV]
  - Max. Propagation Length [100m, 1km]

- Reconstruction
  - 3 resolution settings
  - Smear out energy losses per track segment
  - Smear out propagated length
  - Estimate the muon energy from the track segments

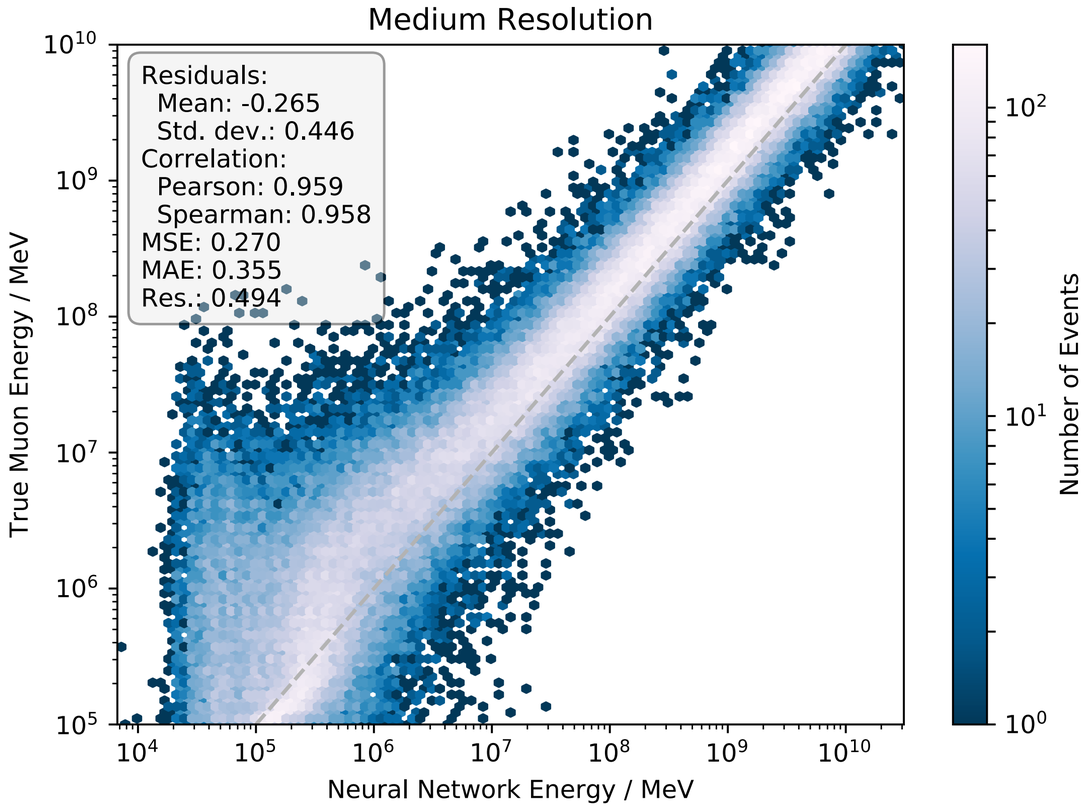


Energy Reconstruction with two independent methods

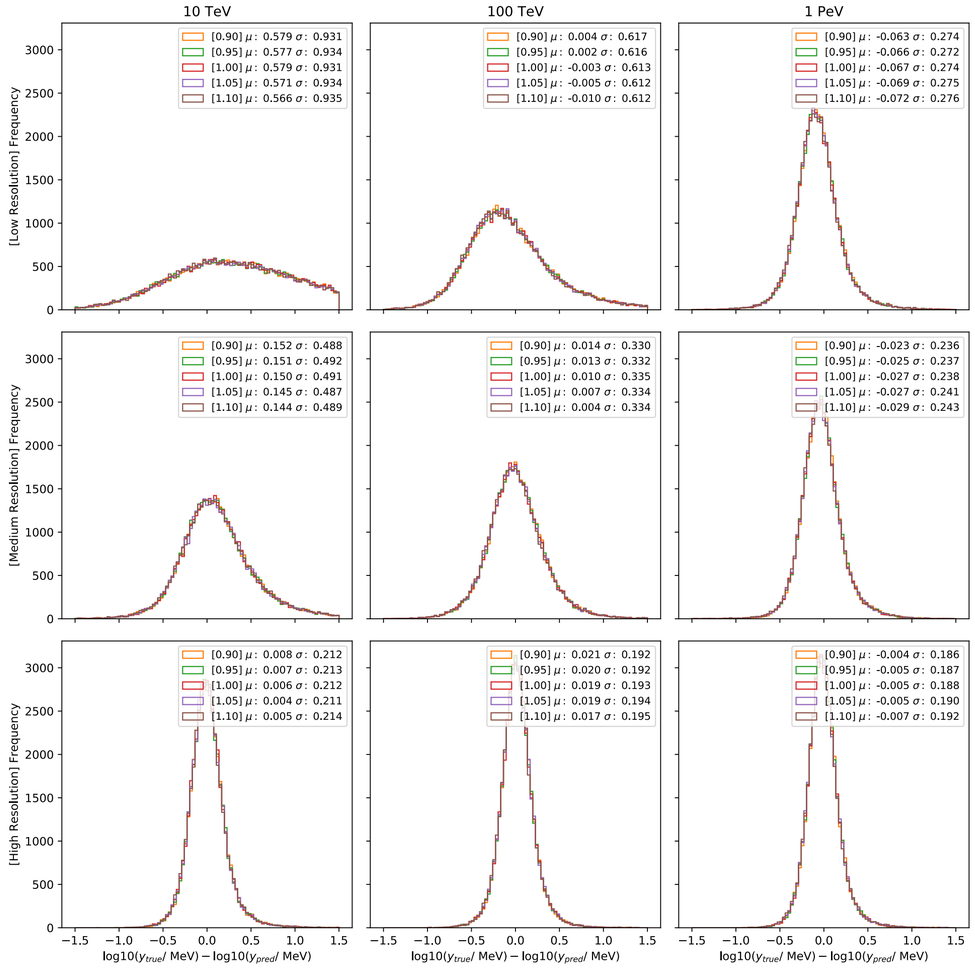
Truncated Energy

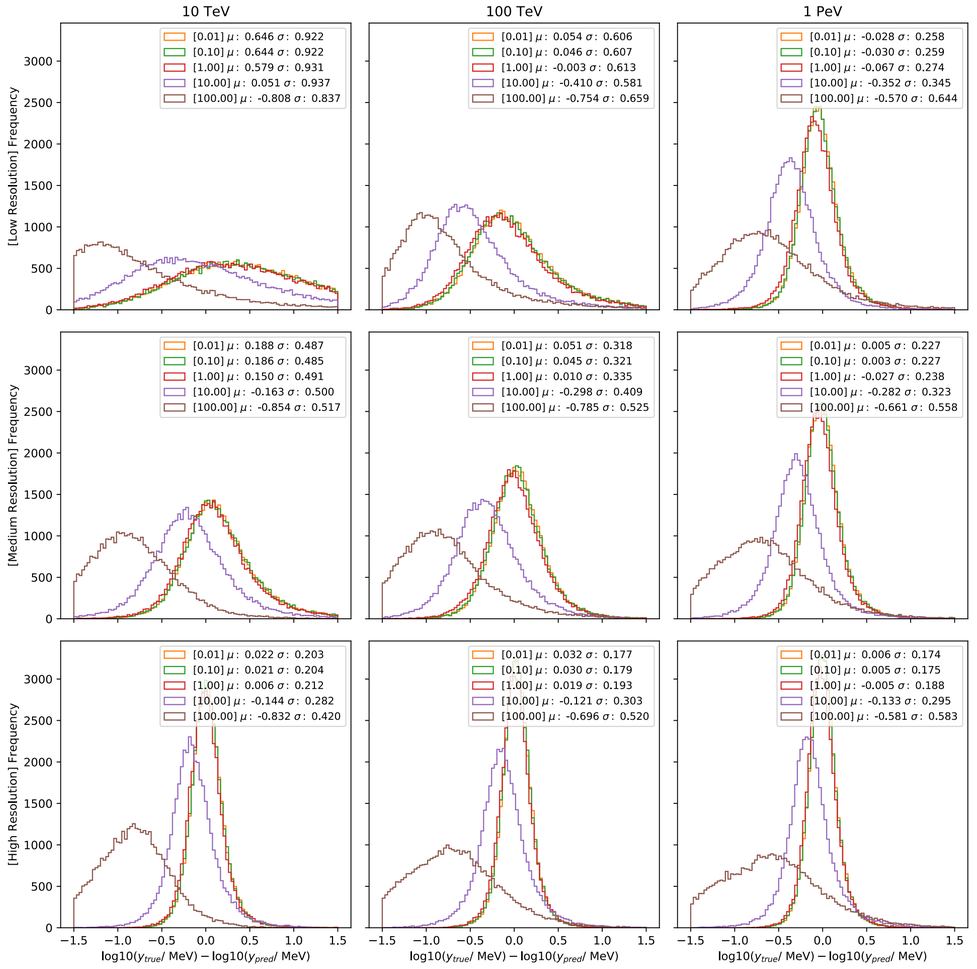


Neural Network



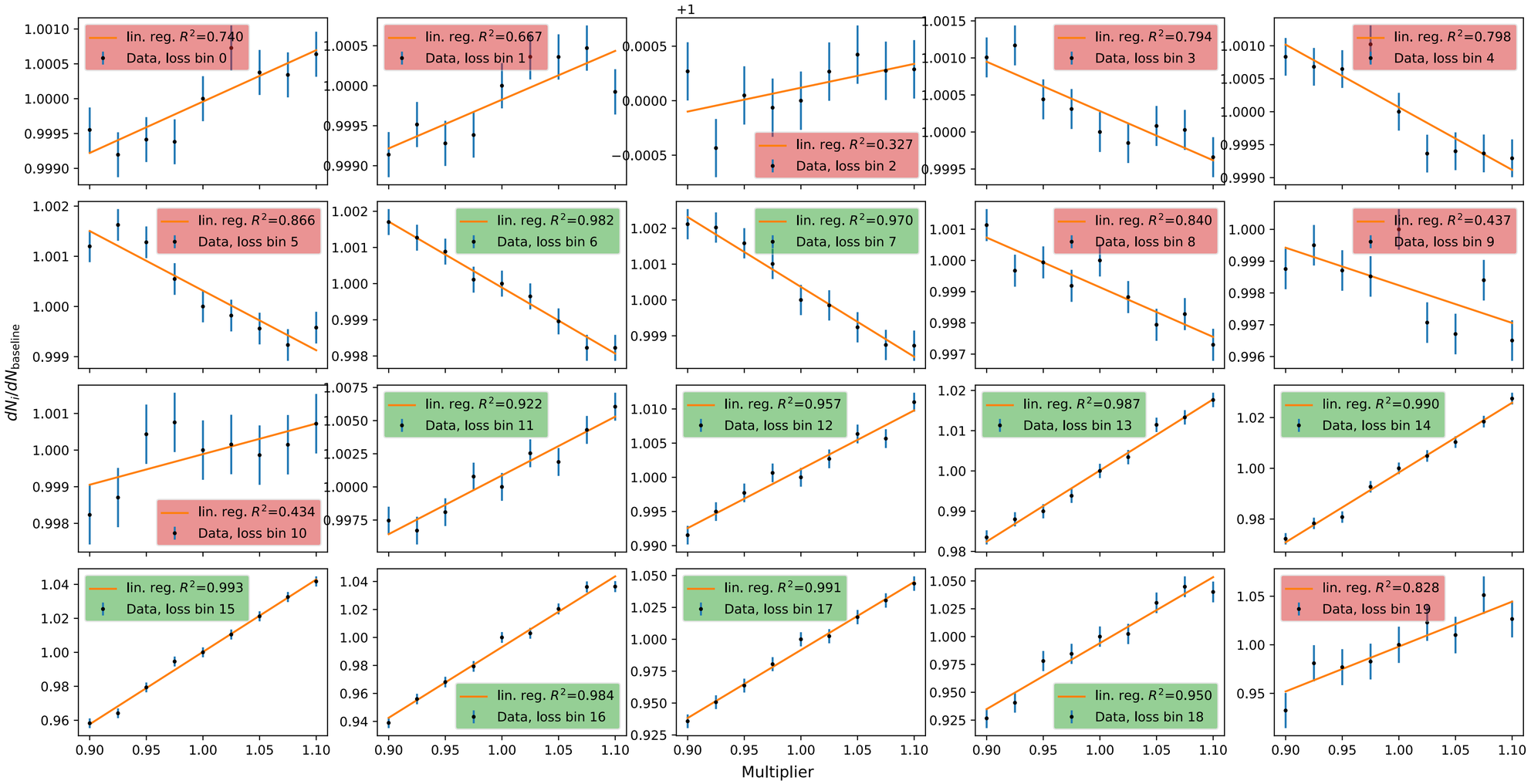
Energy Reconstruction dependence on Bremsstrahlung





Small Changes do not affect the energy reconstruction, just large increases affect the reconstruction.

Interpolation of the differences in each energy loss bin



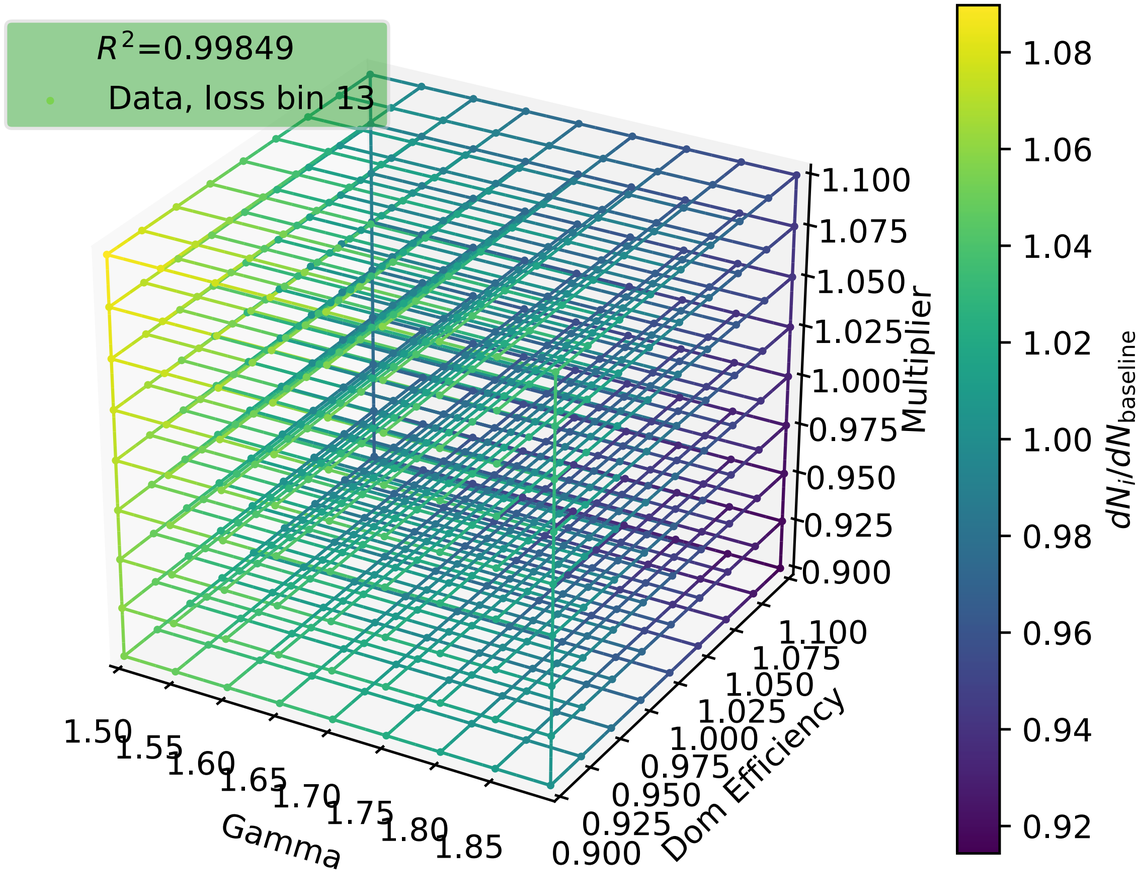
- Using cubic instead of linear Interpolation
- Discard bins without good Interpolation agreement using R^2, coefficient of determination

Further Systematic Parameters

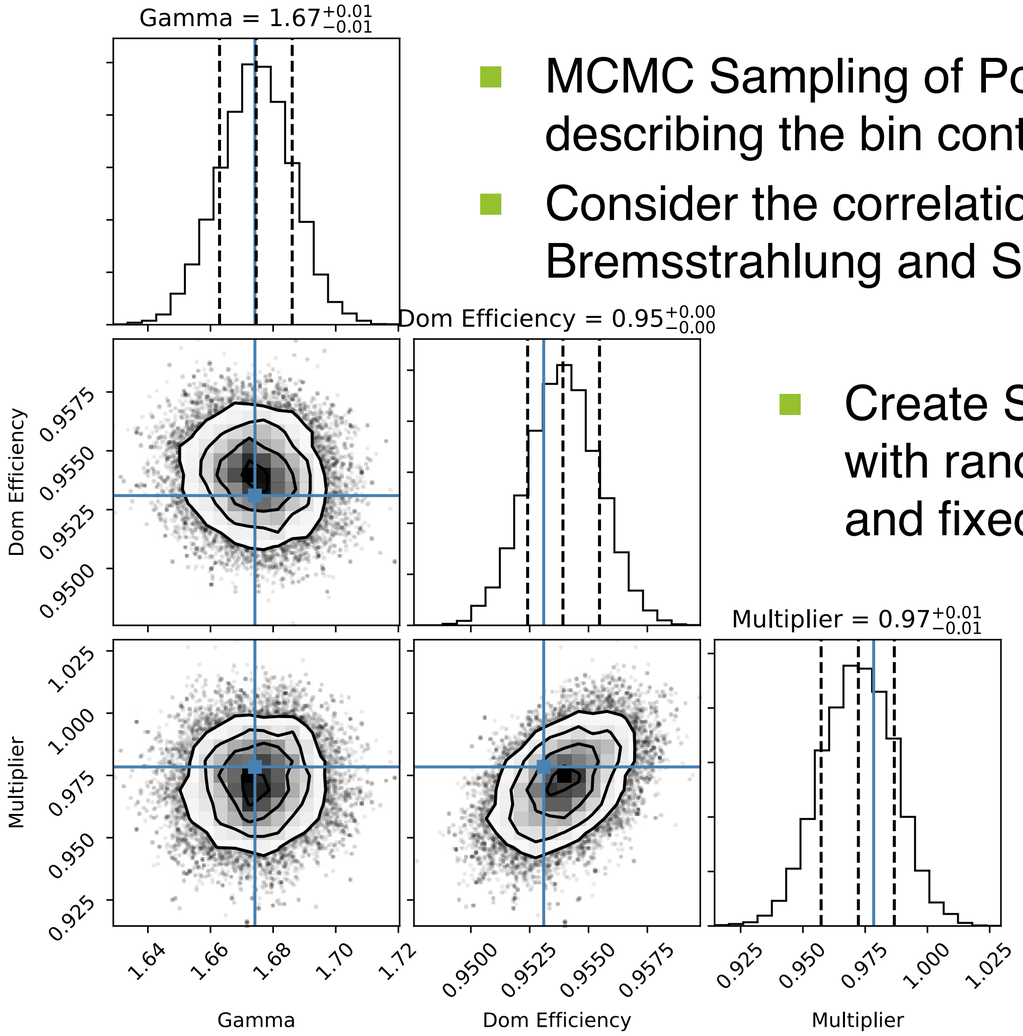
- DOM Efficiency, scaling the reconstructed energy losses
- Spectral Index, weighting the events

➡ 3D interpolation of the bin differences

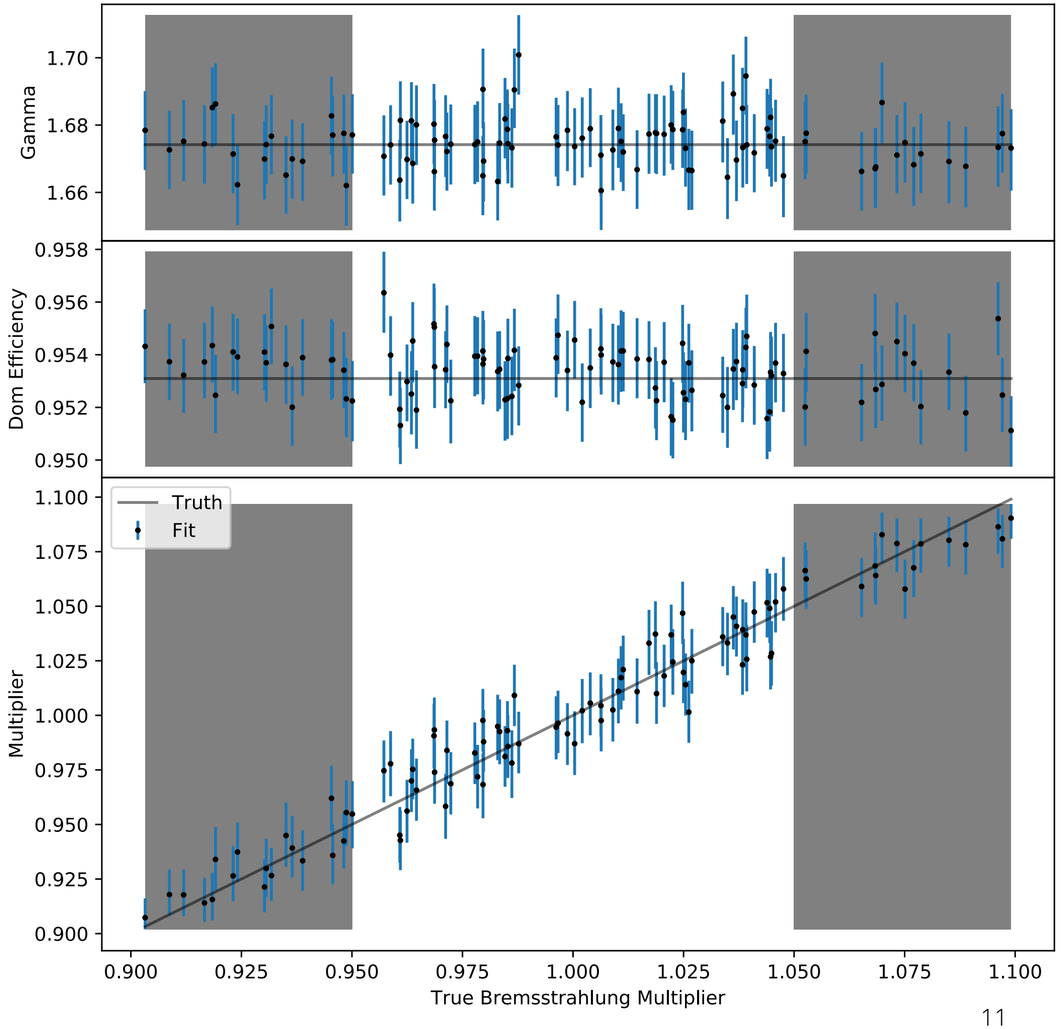
	Bremsstrahlung Multiplier	DOM Efficiency	Spectral Index
Range	[0.9, 1.1]	[0.9, 1.1]	[1.5, 1.9]
Default	1.0	1.0	1.7
Interpolation Order	Cubic	Quadratic	Quadratic



Measurement of the Bremsstrahlung Multiplier and Systematics

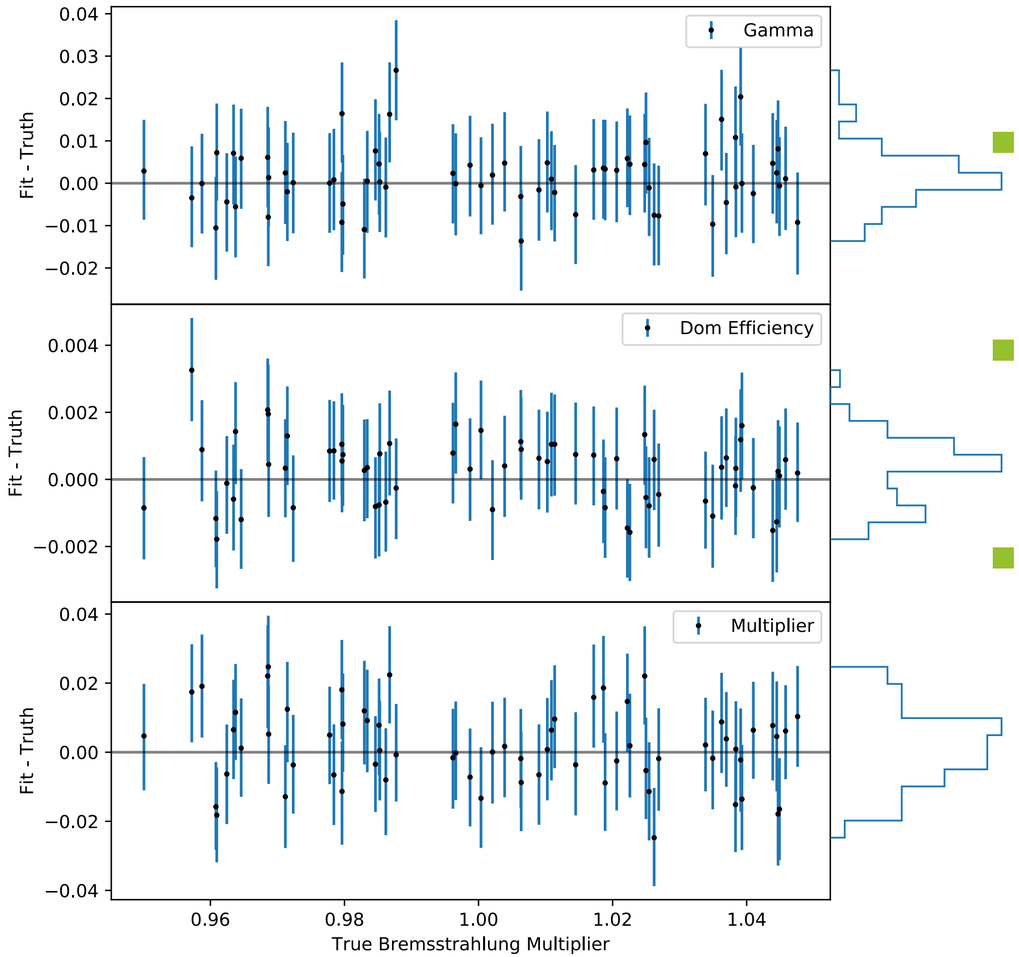


- MCMC Sampling of Poisson LLH describing the bin contents
- Consider the correlation between the Bremsstrahlung and Systematics
- Create Simulations sets with random Multipliers and fixed Systematics
- Shrink area due to boundary effects



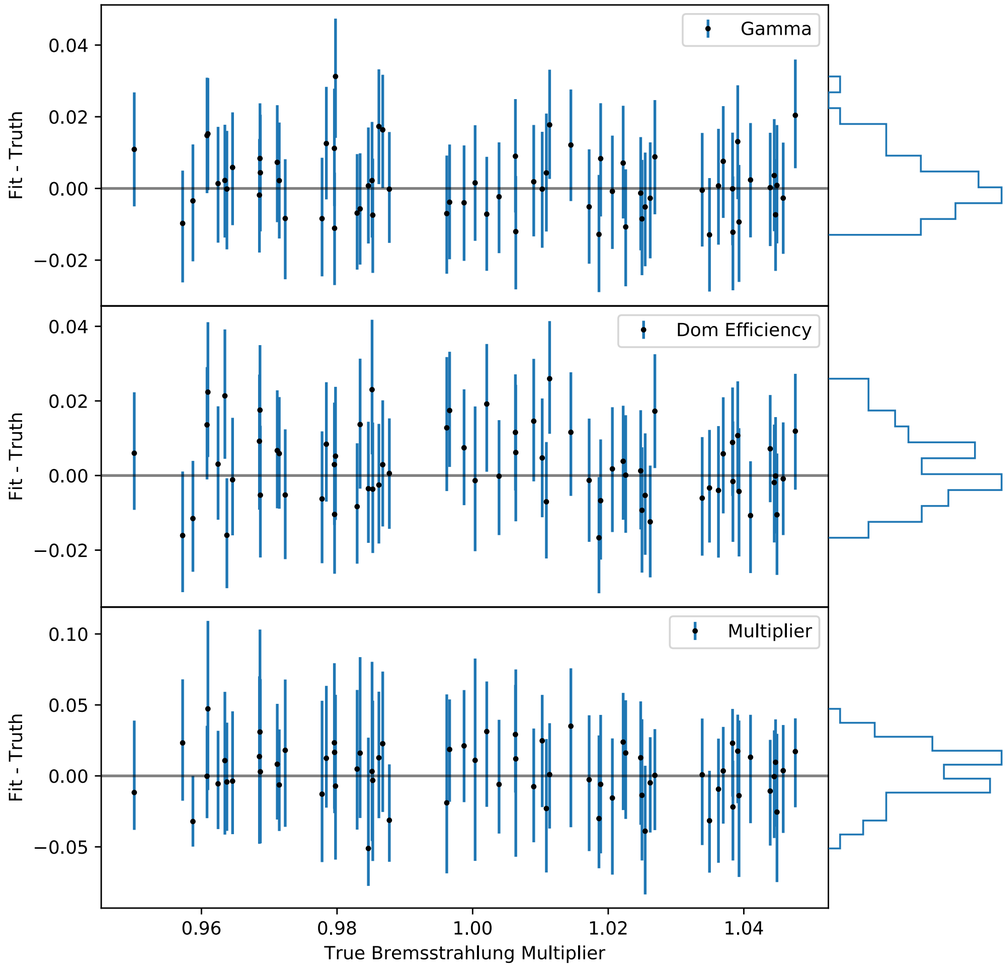
Performance of the Fit

High Resolution



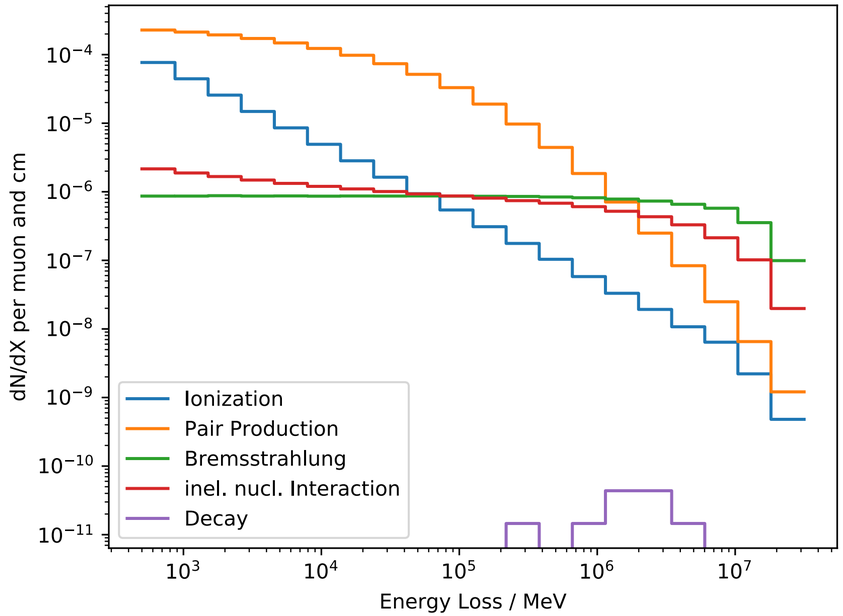
- High resolution
  - ±2% accuracy
- Medium resolution
  - ±4% accuracy
- Low resolution
  - Not feasible

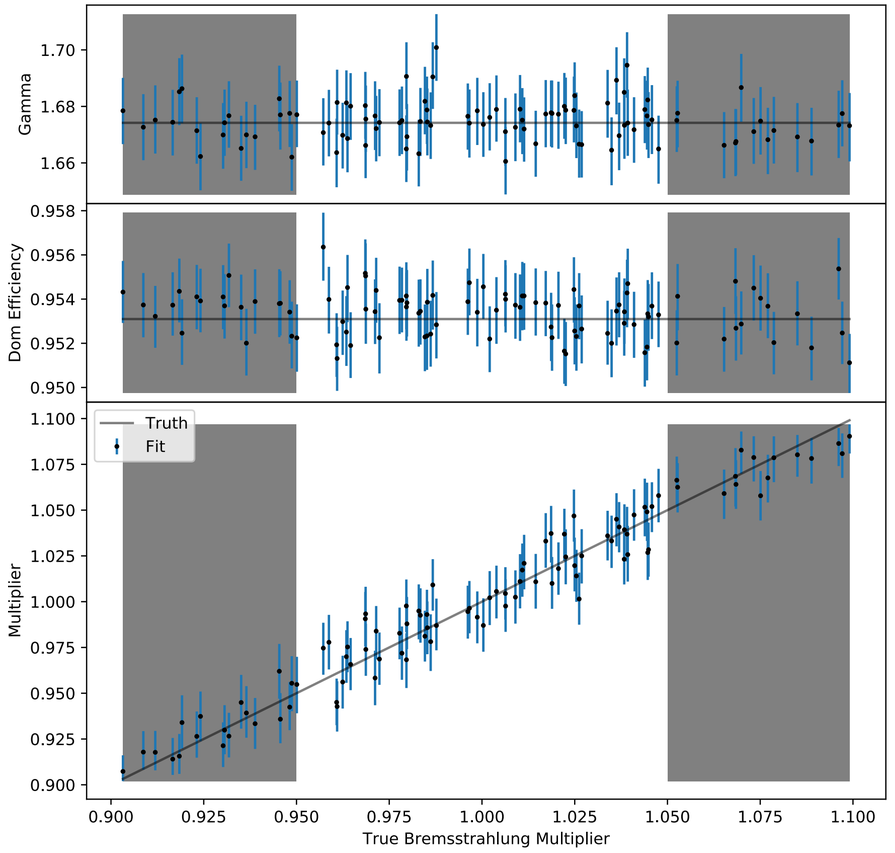
Medium Resolution



Conclusion and Outlook

- Develop toy simulation creating reconstructed energy losses for muon studies just using PROPOSAL
- It is feasible to measure the Bremsstrahlung Multiplier with neutrino telescopes like IceCube using the energy loss profile of neutrino induced muons.
- The energy reconstruction is robust against small changes of the Bremsstrahlung.





- Using also atmospheric muon samples to analyse muons
  - Stopping muons, dominantly arriving as single muons, for lower energies
  - Leading muons, containing most of the bundle energy, for higher energies

End