Error Tolerances and Failure Modes in the ESS Linac

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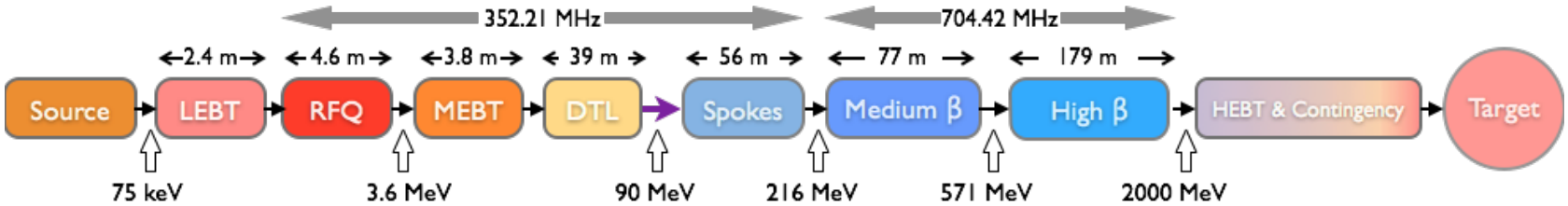
Content

- Overview of the ESS Linac
- What errors we consider
- How we model errors
- How errors scale
- Failure modes
- Discussion points

The ESS Linac



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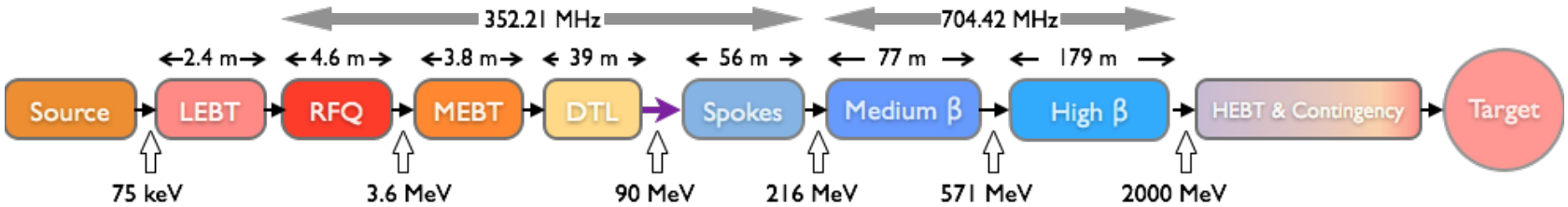

Relevant for this talk are:

MEBT, DTL

Normal conducting errors are applied to the drift tubes, MEBT buncher cavities, and the phase error is also assumed for the beam exiting the RFQ as well.

Spoke, MB, HB

Superconducting errors are applied to all superconducting cavities in the spoke, medium- and high-β cavities. We assume the same error tolerances in all sectors.

Input Parameters (exit RFQ)

Beam current	62.5 mA
Duty cycle	4 %
Transv. emittance	0.25 μm
Beam energy	3.62 MeV
Particles per simulation	10^5
Number of simulations	100

Questions to keep in mind during this talk

- Are the error distributions reasonable?
- Are the error magnitudes reasonable and feasible?
- Should we define more specific errors for the different sectors?

What are static errors?

Static errors are originating primarily from installation, but can also arise from long term drifts, during upgrades and consolidation of problems in the tunnel etc.

- Static errors stay constant for a long period of time, which means we can measure them precisely (multiple shots).
- For beam dynamics, we do not care what the origin of the error is, we care only about how it modulates the electromagnetic field.
- Example: transversal movement of a dipole is not relevant, as long as the beam stays within the good field region. (GFR).

What are dynamic errors?

Dynamic errors are changes which happen faster than the time between corrections/setup.

- Dynamic errors will typically vary randomly, e.g. electrical noise, vibrations, jitter...
- Drifts (e.g. sinking ground floor) are not considered.
- Generally dynamic errors are smaller than static errors.
- Fast dynamic errors (seconds and less) limit our measurement precision of static errors.

What errors we consider

Static	
Magnets	displacement, rotation, gradient
Cavities	displacement, rotation, amplitude, phase
Instrumentation	accuracy
Input Beam	non-centred (incl. phase), emittance, current
Dynamic	
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Definition of phase/amplitude errors

Phase Errors

The phase of the RF field that is **seen** by the bunched beam is off by a defined number of **degrees**.

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The amplitude of the RF field that is **seen** by the bunched beam, is off by a **percentage** of design amplitude.

Default Values

- Normal conducting: 0.2 deg or %
- Superconducting: 0.12 deg or %
- Static: 1.0 deg or %

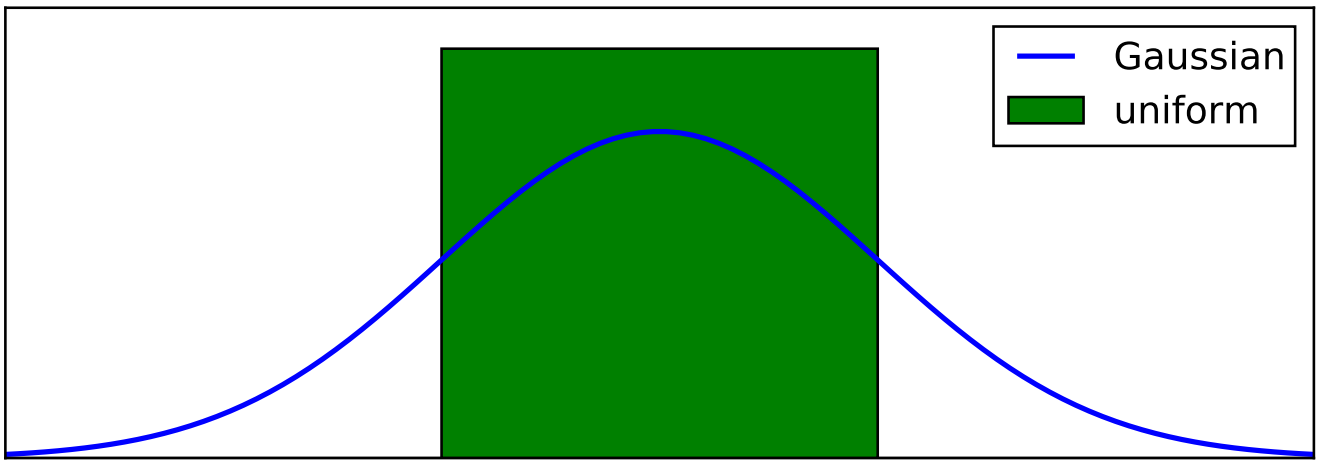
Error distributions

Static Errors

Static errors are distributed **uniformly** within the margins defined.

Dynamic Errors

Dynamic errors are **Gaussian distributed** with the σ_{err} equal to margin defined.



Evaluating simulations

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INDIRECT: Errors introduce additional growth of beam size (emittance), which in reality translate to increased losses.

Requirement: Losses should not exceed 1 W/m, emittance growth approx 10 % per sector or less.

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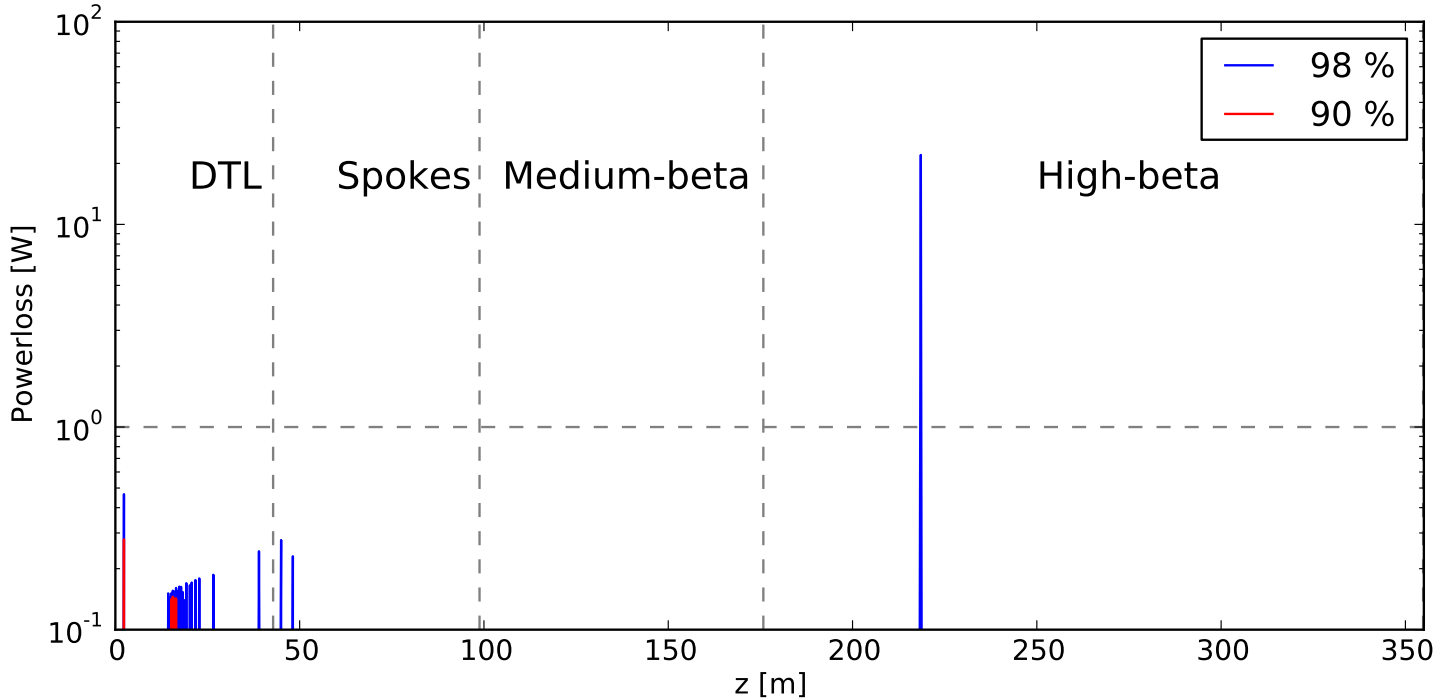
- Additionally, phase/amplitude errors of cavities
- **Please note: Not showing HEBT, did not have a well matched lattice available in time for this workshop**

Results

Please consider the results preliminary.
More statistics are needed for final conclusions.

Results



Losses with current baseline error tolerances

How errors scale

The cases we have simulated (% / deg):

	NC	SC
1	0.0	0.0
2	0.2	0.12
3	0.3	0.12
4	0.4	0.12
5	0.4	0.2
6	0.5	0.2
7	0.6	0.3

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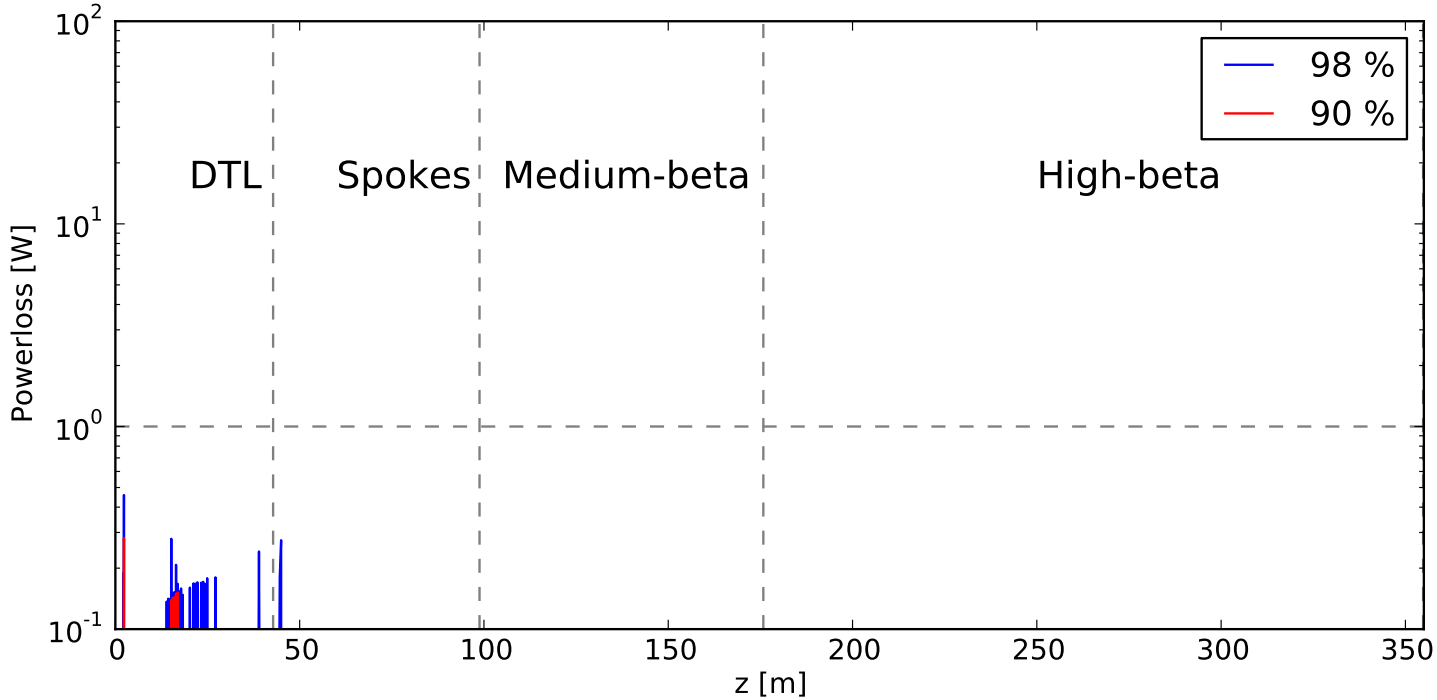
7	0.6	0.3

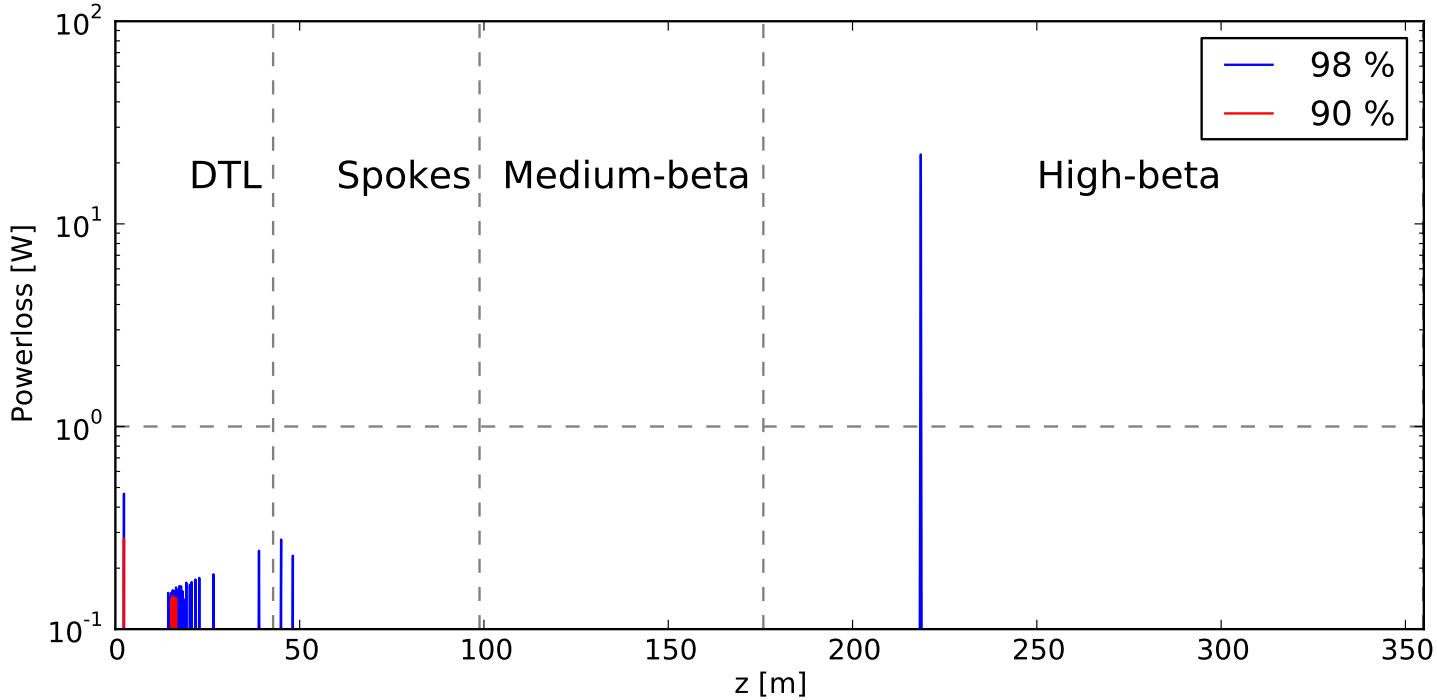
Our current baseline

How errors scale



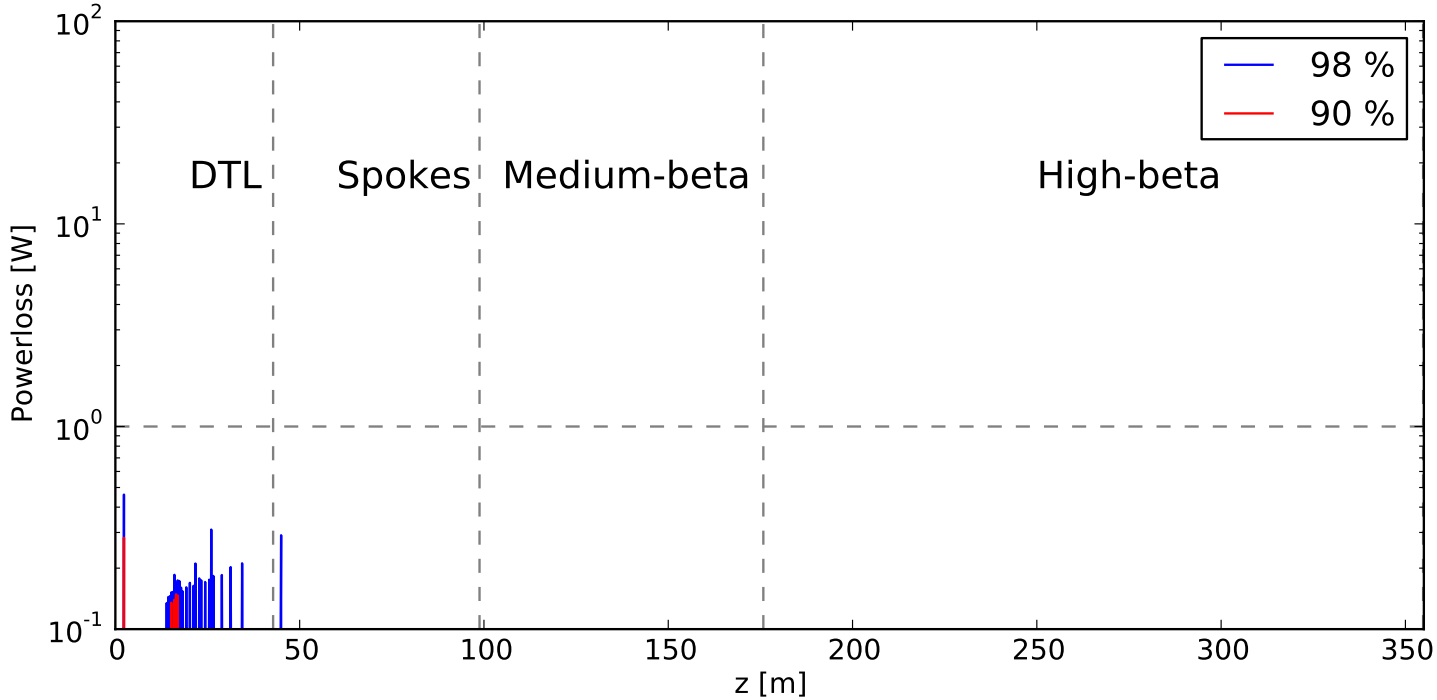
	NC	SC
1	0.00	0.00

How errors scale



	NC	SC
2	0.20	0.12

How errors scale



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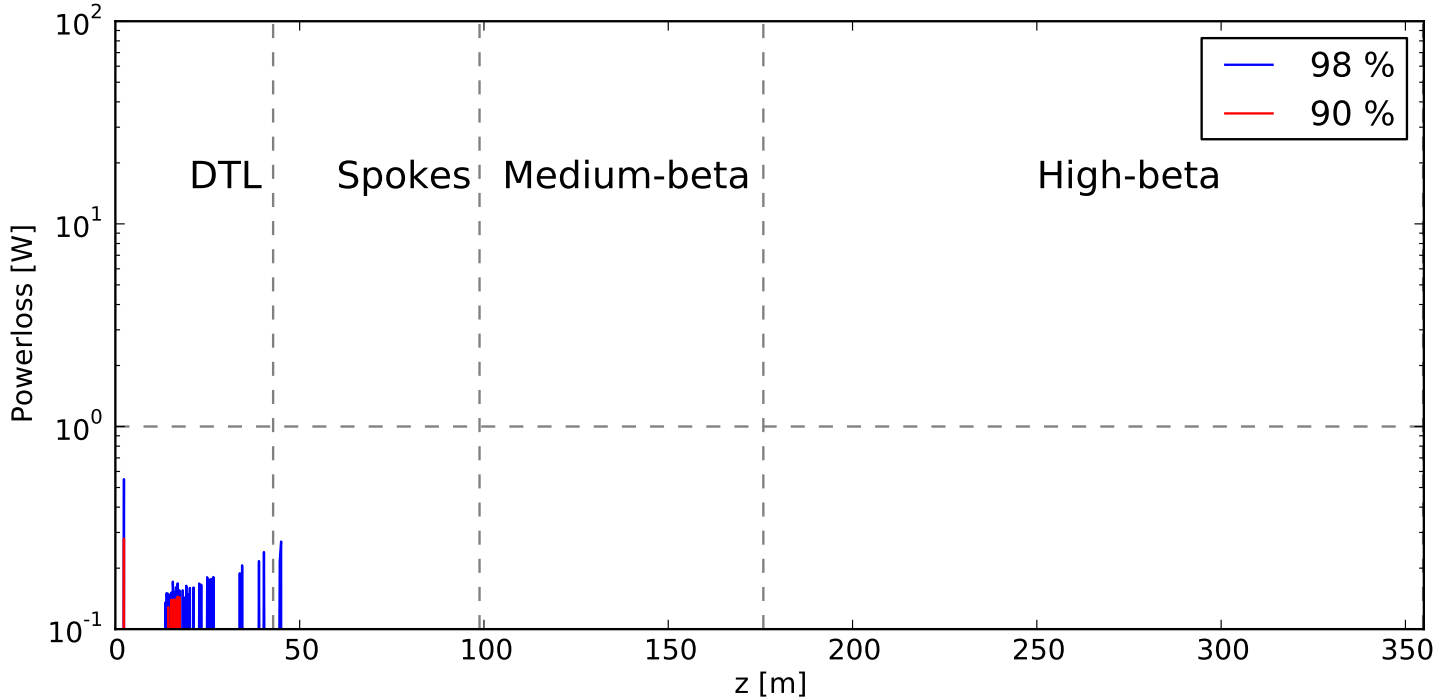
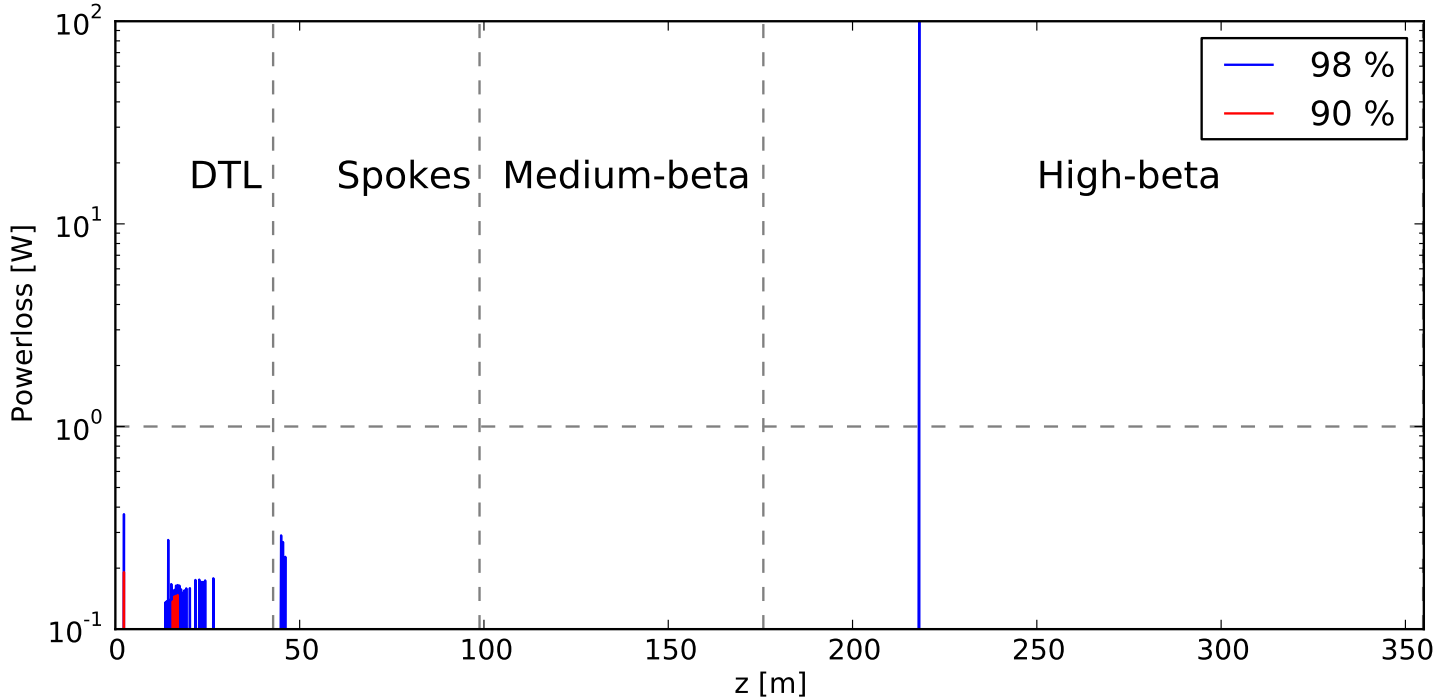


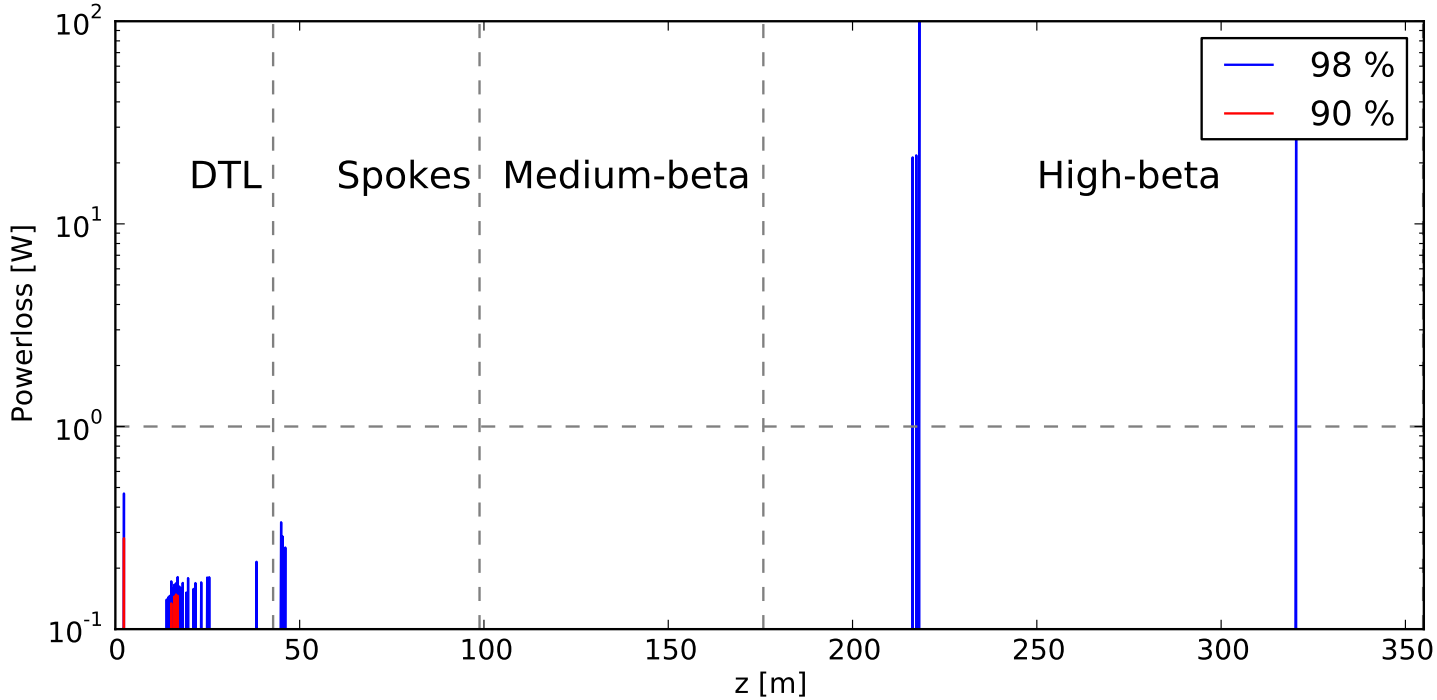
	NC	SC
4	0.40	0.12

How errors scale



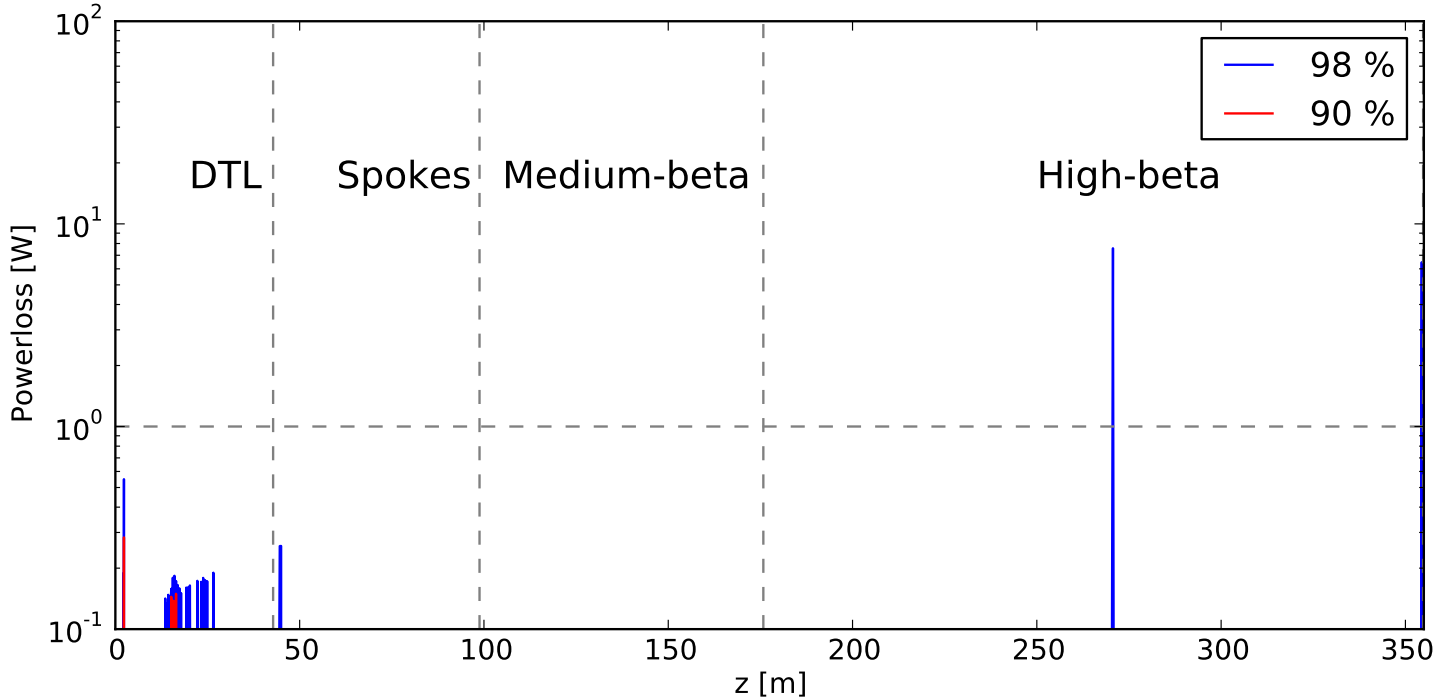
	NC	SC
5	0.40	0.20

How errors scale



	NC	SC
6	0.50	0.20

How errors scale



	NC	SC
7	0.60	0.30

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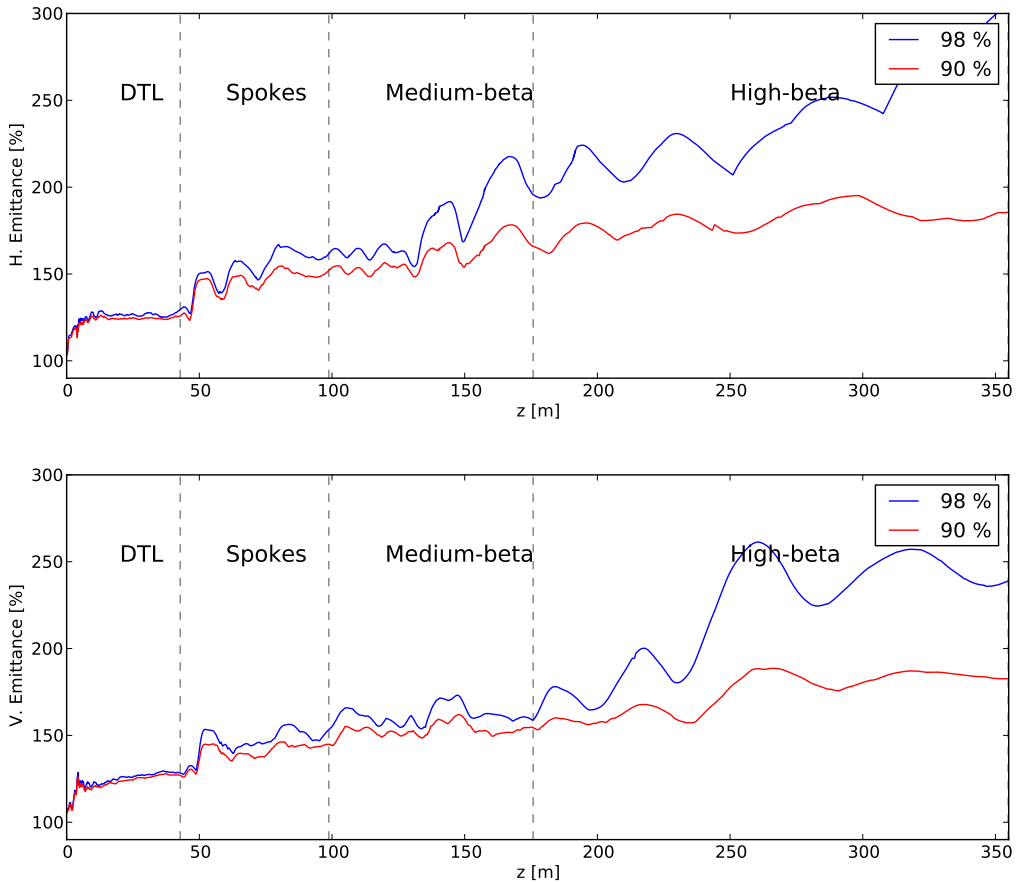

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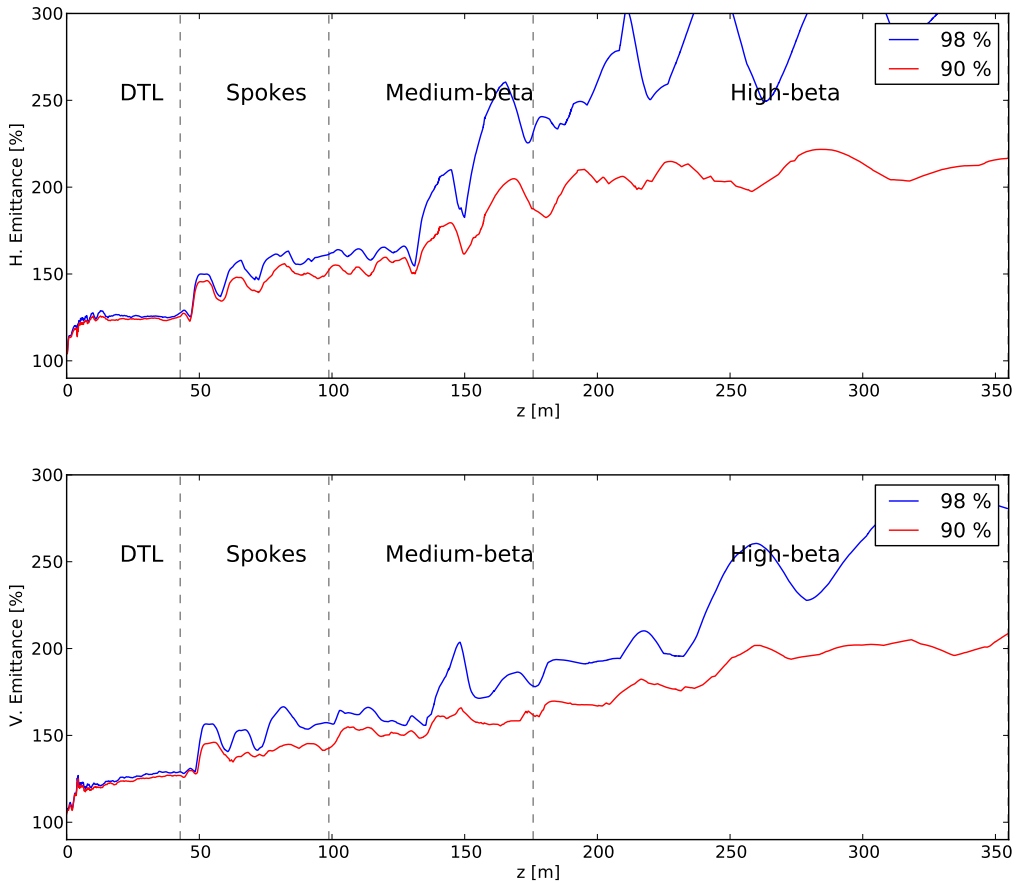

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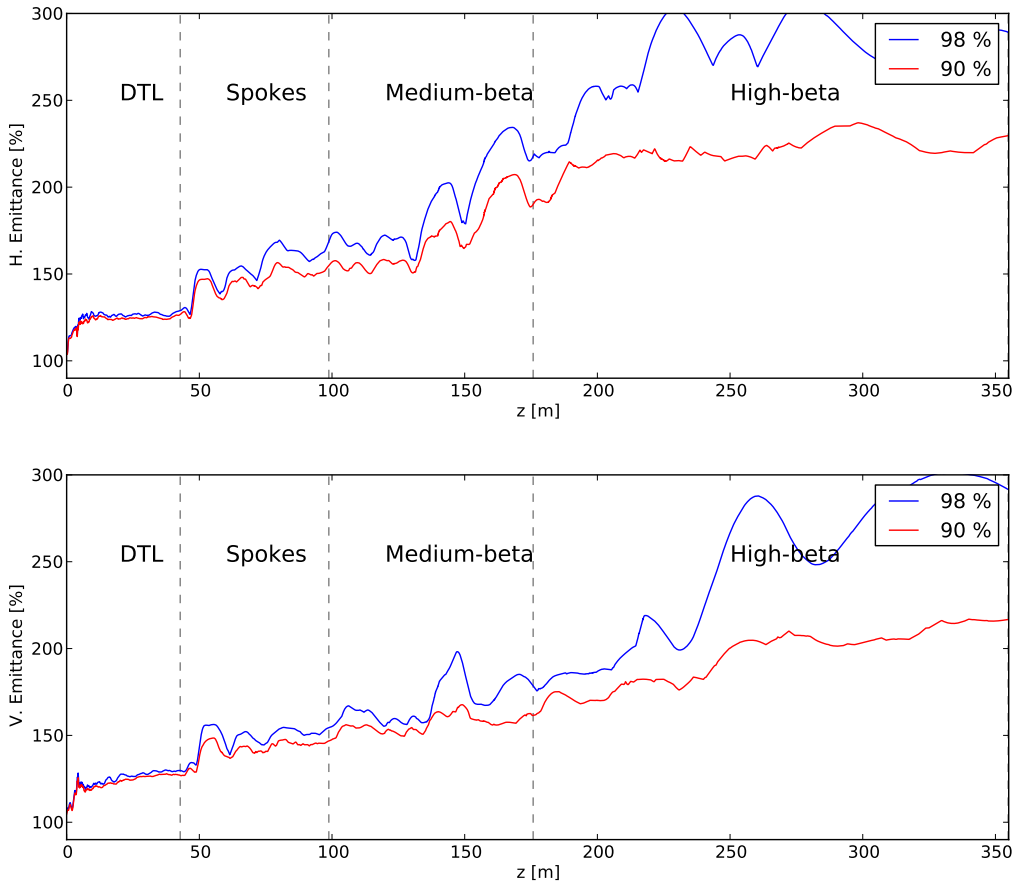

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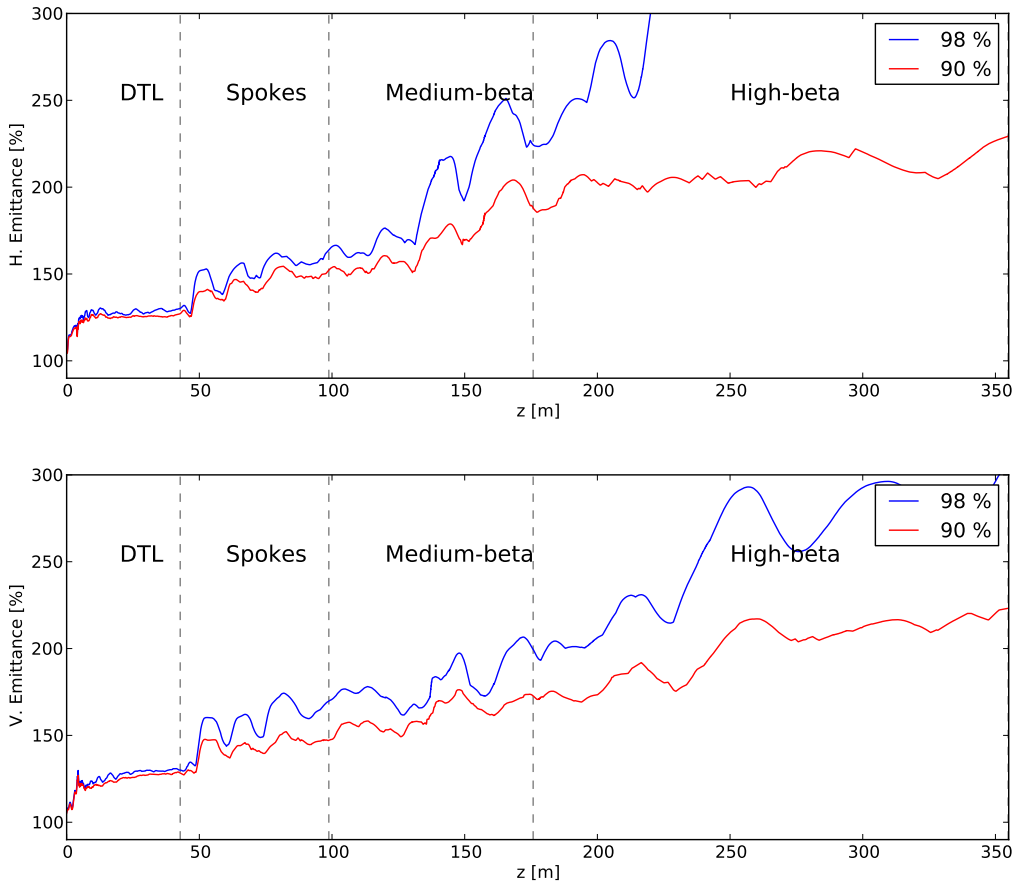

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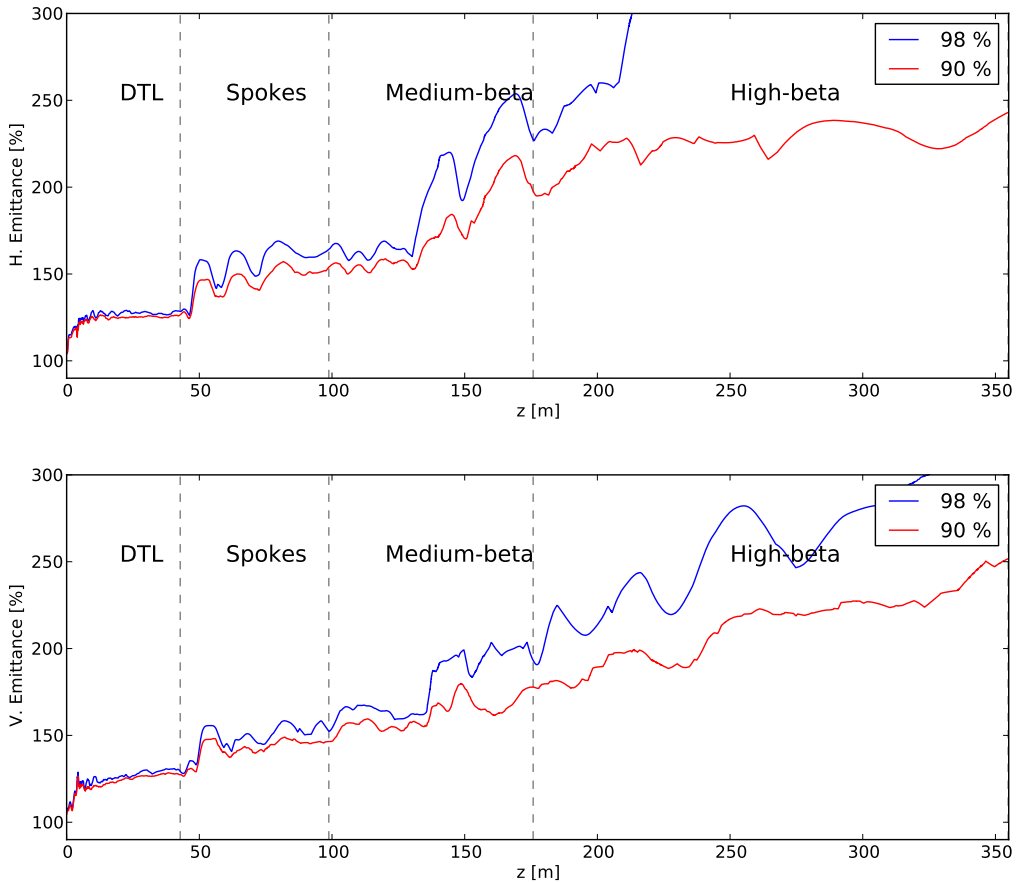

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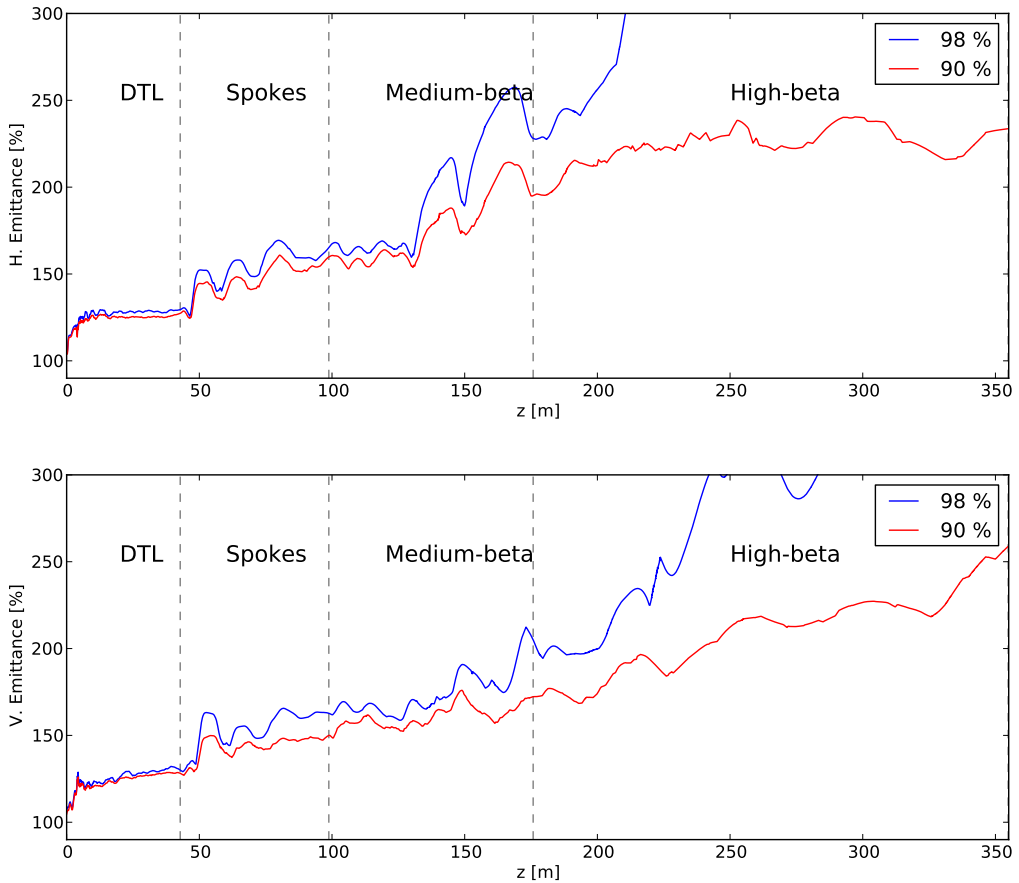

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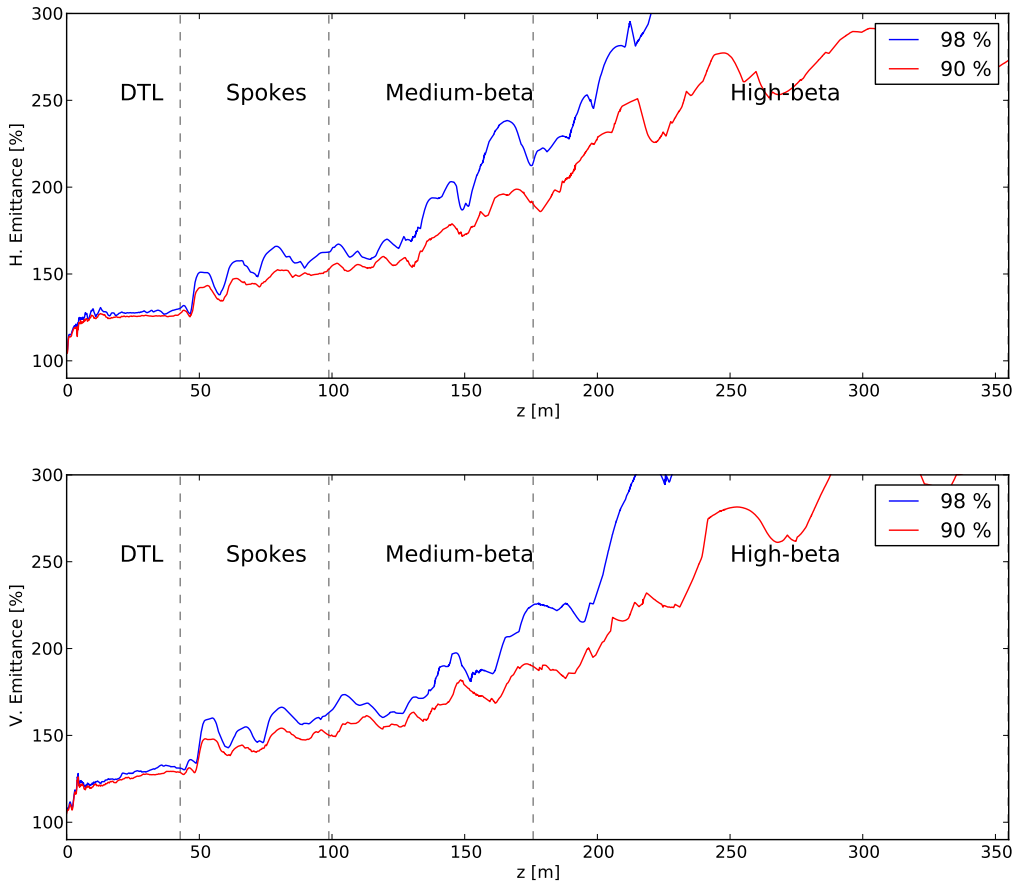

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How errors scale

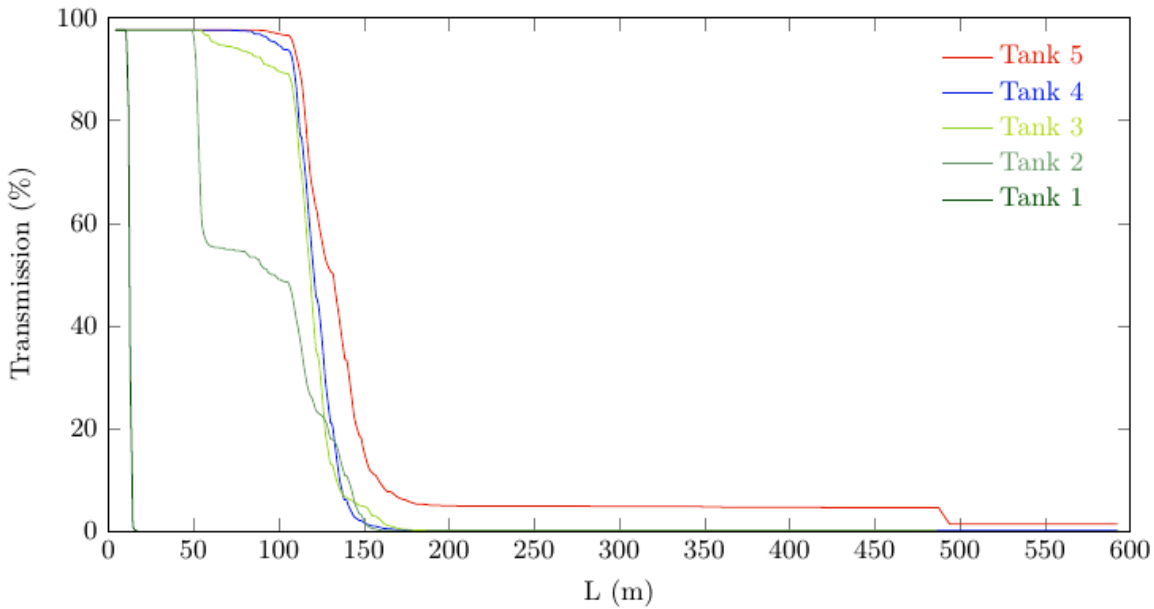
Remember that ...

- ... the HEBT is not shown here.
- ... we need to leave margin for error/simulation uncertainty/parameter uncertainty.
- ... the final conclusion from these studies require higher level of statistics.

Failure modes

What happens when a cavity fails? (e.g. breakdown)

MEBT and DTL failures



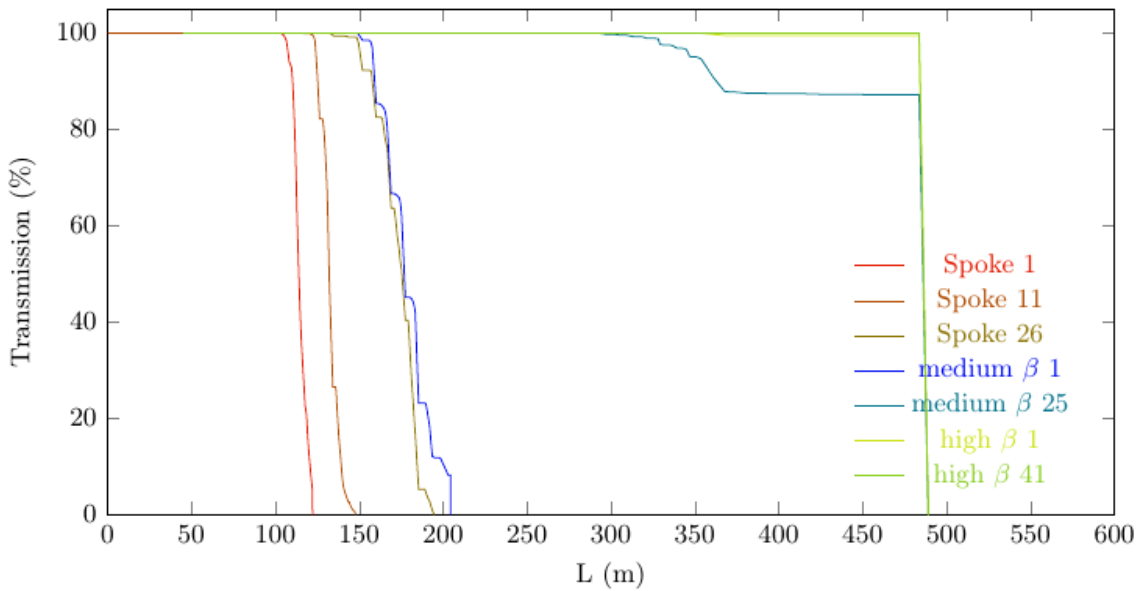
MEBT Buncher Cavity

Complete failure cause losses on the 100 W level downstream. Scrapers not helpful as this is a longitudinal blowup.

DTL Tanks

No power in one DTL tank cause losses on the 1000 W level downstream. Tank 1 -> all lost in DTL, tank 3-5 -> losses in SC only.

SC Cavity failures



Spoke, MB, HB Cavities

Complete failure of a SC cavity cause losses on the 10 kW level downstream, with peak in dogleg of up to 1 MW. For last high-β, some transmission to target.

Summary

- An extensive simulation framework is available for beam dynamics error studies.
- RF field amplitude/phase errors may significantly increase losses in the linac.
- Difficult based on current simulation results to conclude that we can relax tolerances.

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- An extensive simulation framework is available for beam dynamics error studies.
- RF field amplitude/phase errors may significantly increase losses in the linac.
- Difficult based on current simulation results to conclude that we can relax tolerances.
- 0 field in one DTL tank or SC cavity (mostly) results in lost beam.
- Time structure of failure not considered.
- Partial failure not considered.

Discussion points

- Are there ignored errors which will be important?
- Are the error distributions reasonable?
- Are the error magnitudes reasonable and feasible?
- Should we define more specific errors for the different sectors?

References

- M. Eshraqi et al, TAC'09
- M. Eshraqi et al, Chess document ESS-0031413
- M. Eshraqi et al, IPAC'14: *"Statistical Error Studies in the ESS Linac"*
- Y. Levinsen et al, IPAC'15