planning 2022 lectures Reliability

Monday 14 november 2022 green = activing element

13:45-14:00 introduction SE Track Base by Dr. Ravenshorst

14:00-14:25 part 1 t/m part 4 (slide 1-28)

14:25-14:30 calculate reliability index β for given example (slide 29)

pauze

14:45-14:55 part 5 consequence classes (slide 30-34)

14:55-15:10 part 6 partial safety factors (slide 35-60)

15:20-15:30 part 7 combination factors (slide 61-73)

Thursday 17 november 2022

08:45-09:15 part 8 and 9 service life, ULS/SLS, load combinations (slide 74-78)

09:15-09:30 recap / in-class exercise with load combinations

09:45-10:30 Dr. Ajay Jagadeesh (pavement)

1. INTRODUCTION
2. STRUCTURAL SAFETY AND ACCEPTED RISKS
3. EUROCODE APPROACH
4. PROBABILITY OF FAILURE
5. CONSEQUENCE CLASSES
6. PARTIAL SAFETY FACTORS
7. VARIABLE LOADS
8. DESIGN SERVICE LIFE
9. LIMIT STATES
10. LOAD COMBINATIONS

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Reliability
Lecture 2.1.1 + 2.1.3a

Faculty of Civil Engineering and Geosciences
MSc Civil Engineering

module: SE-TB-1 Sustainable Construction Members and Systems

Dr. Roel Schipper

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CONTENT OF THE LECTURE

1. **INTRODUCTION**
2. STRUCTURAL SAFETY AND ACCEPTED RISKS
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Learning objectives of these lectures

- Understand the **concepts of reliability** and apply these in practical verification of the safety (lecture 2.1.1 and 2.1.3a)
- **Identify** and **quantify** the most important loads on **structures**, **roads** and **railway** (lecture 2.7.1)
- **Schematise** and **combine** them as input for the determination of the **force** distributions and **deformations** (lecture 2.7.3)

Assessment

- Formative (no grade) homework assignment on Load Analysis for a container port terminal (week 2.1)
- Formative (no grade) homework assignment on Reliability (week 2.7)
- Part of written exam (approx. 20 minutes) (week 2.10)

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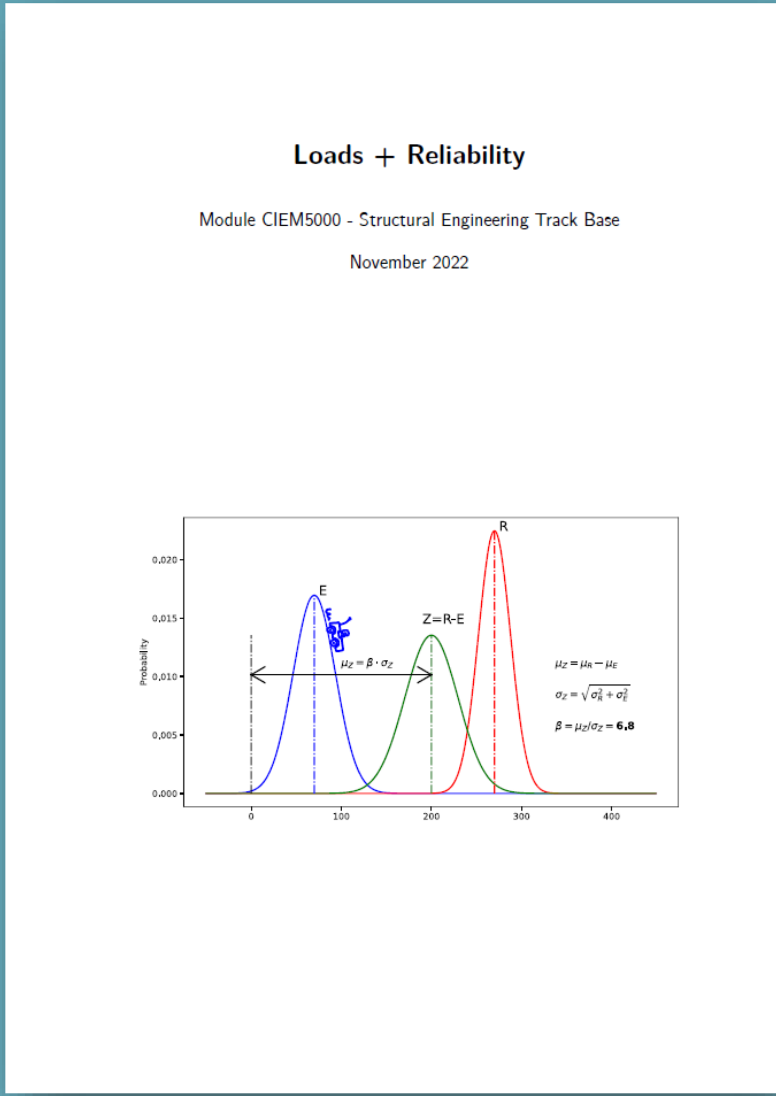
Reference materials

- **Lecture notes** "Loads + Reliability", Module CIEM5000 – Structural Engineering Track Base, November 2022 (PDF, Brightspace: study this reader)
- **Eurocodes**
  (online, for information and reference only)
- **Quick Reference** 2022
  (PDF, Brightspace, for reference only)


Loads + Reliability

Module CIEM5000 - Structural Engineering Track Base

November 2022

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Voluntary and involuntary risks

	cause	risk of dying (yearly)
voluntary risk	flying	$0.4 \cdot 10^{-6}$
	lethal accident while driving a bicycle	$13 \cdot 10^{-6}$
	lethal accident while driving a motorcycle	$5.5 \cdot 10^{-6}$
	drowning while swimming	$6.1 \cdot 10^{-6}$
	smoking	$1100 \cdot 10^{-6}$
involuntary risk	covid-19 (during 2020)	$1100 \cdot 10^{-6}$
	attack by an animal	$0.2 \cdot 10^{-6}$
	exposure to fire or smoke	$3.0 \cdot 10^{-6}$
	natural disaster, lightning, storm, floods	$0.03 \cdot 10^{-6}$
	gun violence	$1.5 \cdot 10^{-6}$

(number of yearly casualties in The Netherlands - risk is determined by number of cases divided by **total** population of approx. 17.6 million, CBS StatLine 2022)

Voluntary and involuntary risks

"In The Netherlands, as a starting point it is assumed that the **risk from a hazardous activity** to a member of the public **should not add significantly** to the risk in every day life.
The risk in every day life is taken as **$P = 10^{-4}$**, the **probability of death for an unspecified individual person per year**"
(Ale, 1991)

"For **new hazardous installations** the maximum acceptable level for individual risk was set to **$P = 10^{-6}$**, which implicates an increase of the risk in every day life of **1%**"
(Ale, 1991)

"For **existing structures**, an individual risk of **$P = 10^{-5}$** for death of an individual person due to failure of a structural element is considered acceptable"
(Vrouwenvelder and Scholten, 2008)

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Voluntary and involuntary risks

"For the **risk of flooding**, which can have massive consequences in terms of loss-of-life and economy, generally an individual risk limit **between P = 10^{-5} and 10^{-6}** was used for the design of **hydraulic structures** and **dikes**"

"In 2013 the Ministry of Infrastructure and the Environment proposed to use an individual risk **P = 10^{-5}**. The Ministry explained that this choice was made because this risk is **caused by nature**, which is **harder to influence** than a **manmade hazard**. In addition, it was explained that a level of P = 10^{-6} for the entire area of the Netherlands would **not be cost-effective**"

(Terwel, 2014)

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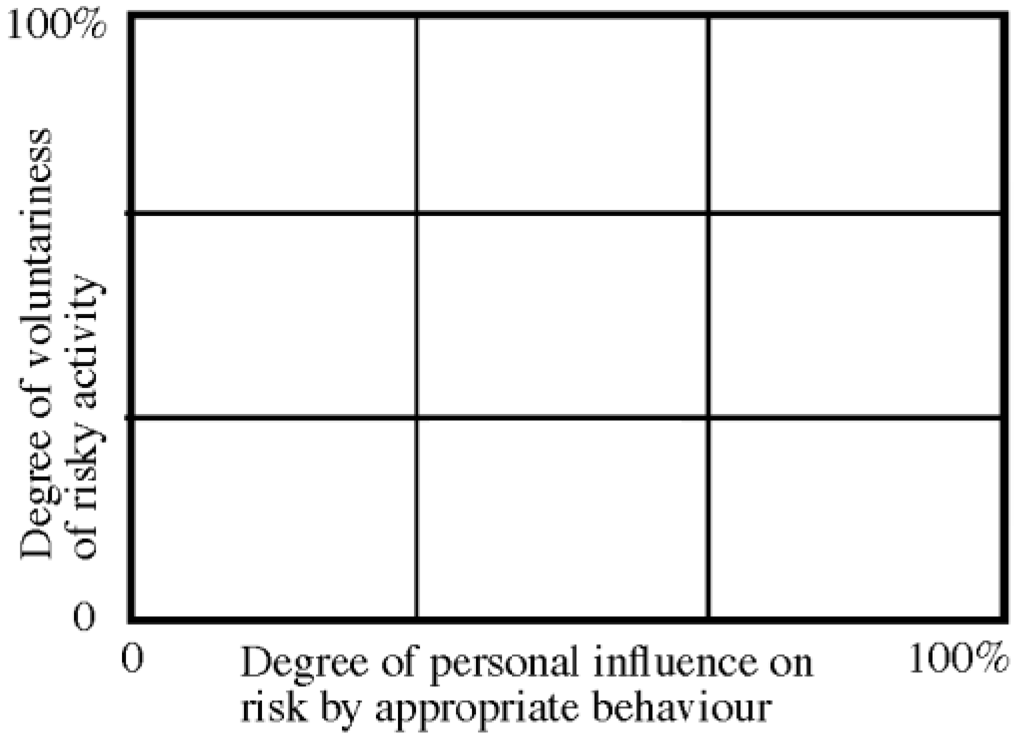
Different activities



Voluntary and involuntary risks

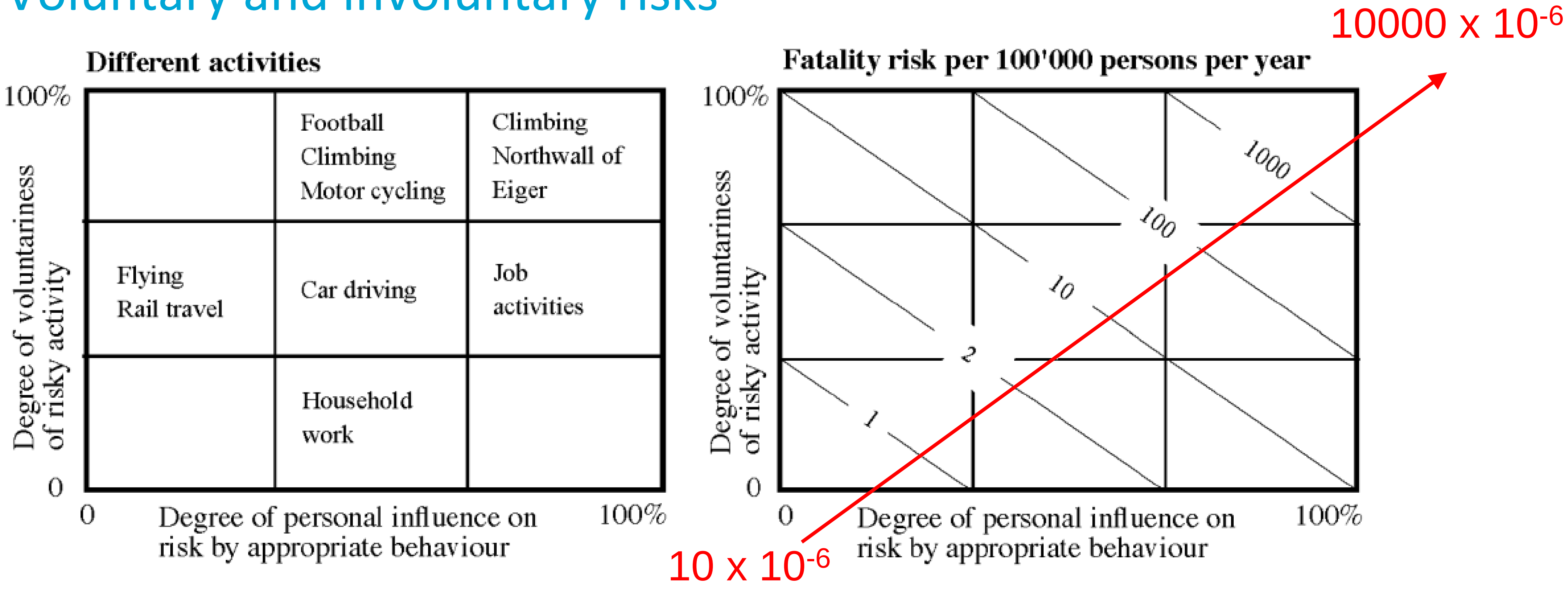


Figure 2.1: Fatality risk per 100 000 persons per year for different activities, related to degree of voluntariness and degree of influence on the risk (Schneider and Vrouwenvelder 2017)

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Voluntary and involuntary risks

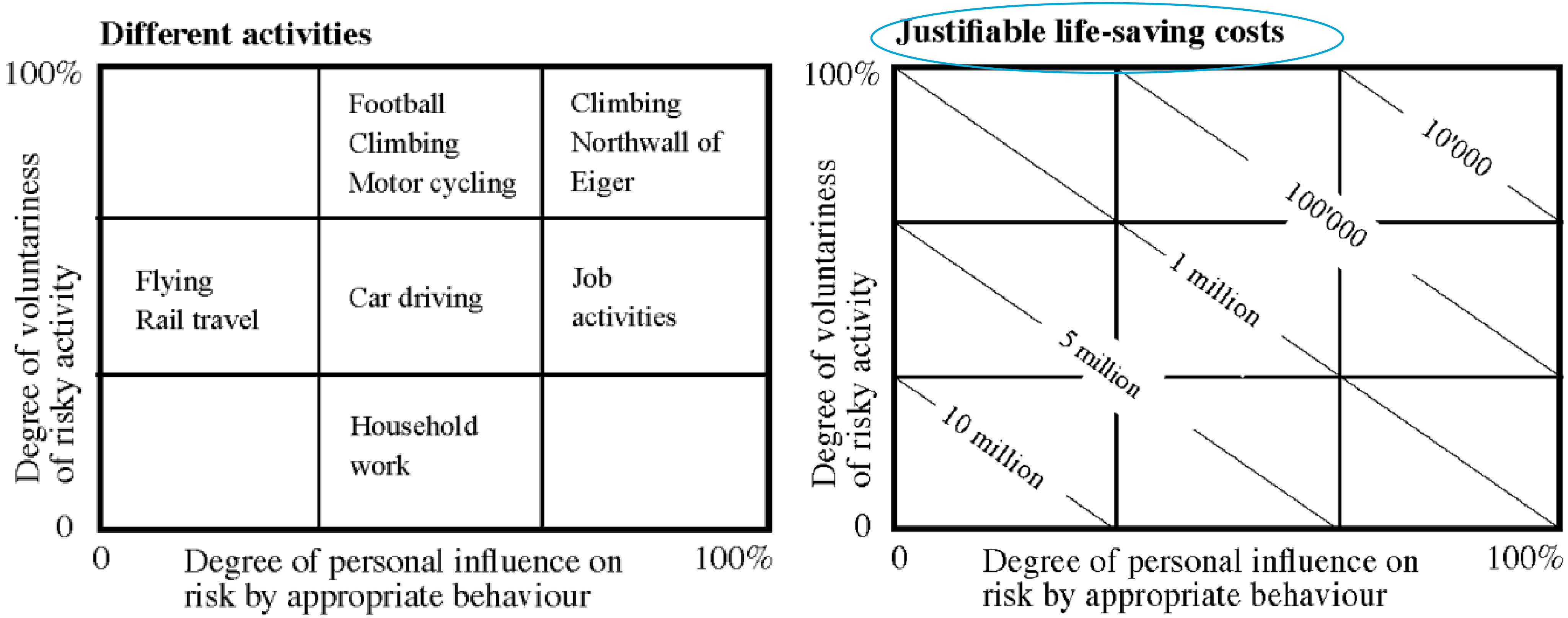

Figure 2.2: Justifiable costs to prevent loss of life and limb. The monetary unit can be read as €, CHF, US$, and £ in 2016, given the bandwidth / limited accuracy of the provided numbers (Schneider and Vrouwenvelder 2017)

Voluntary and involuntary risks - conclusions

Acceptable individual yearly risk as result of structural failure $\approx P_f = 10^{-5}$

At least four factors affect the accepted level of risk:

1. expected **consequences** of a failure
2. **voluntariness** of undergoing the risk
3. possibilities to **reduce** the risk
4. **cost-effectiveness** of reducing the risk

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Methods for the verification of adequate reliable performance of structures

method	applied when
Semi-probabilistic approach Safety format prescribing the design equations and the analysis procedures to be used	Default method in the Eurocodes, i.e. to be used for usual design situations.
Reliability-based design and assessment Reliability requirements to fulfil	Unusual design situations in regard to uncertainties, Code calibration.
Risk-informed decision making Decisions are taken with due consideration of the total risks (e.g. loss of lives, injuries)	Exceptional design situations in regard to uncertainties and consequences. Derivation of reliability requirements.

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Risk-informed decision making

Exceptional design situations in regard touncertainties and consequences or derivation of reliability requirements.

example:
storm surge barrier Oosterschelde

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Reliability-based design and assessment

Unusual design situations in regard to uncertainties, code calibration

example:
working in construction materials for which no code is available

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Reliability-based design and assessment

Unusual design situations in regard to uncertainties, code calibration

example:
working in construction materials for which no code is available

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Reliability-based design and assessment

Applied to design situations where **uncertainties** in the representation of **loads**, load **effects**, **material** resistances, and **system-effects** mean that the reliability-based approach gives a significantly better representation of reality than the semi-probabilistic approach:

- situations where relevant **loads or hazard scenarios** are not covered by the loads and actions described in the code
- the use of building materials or combination of different materials **outside the usual application domain**
- **new materials**, behaviour at very high temperatures
- **ground conditions**, such as rock, which are strongly affected by discontinuities and other geometrical phenomena

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Semi-probabilistic approach

Default method in the Eurocodes, i.e. to be used for usual design situations.

Methods for the verification of adequate reliable performance of structures

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Probability of failure P_f and reliability index β

Table 2.3: Relation between failure probability P_f and reliability index β (prNEN-EN-1990 2021, table C.2)

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}
β	1.28	2.33	3.09	3.72	4.26	4.75	5.20	5.61

Probability of failure P_f

reliability index β

Eurocode: $P_f \sim 10^{-\beta}$

order of magnitude

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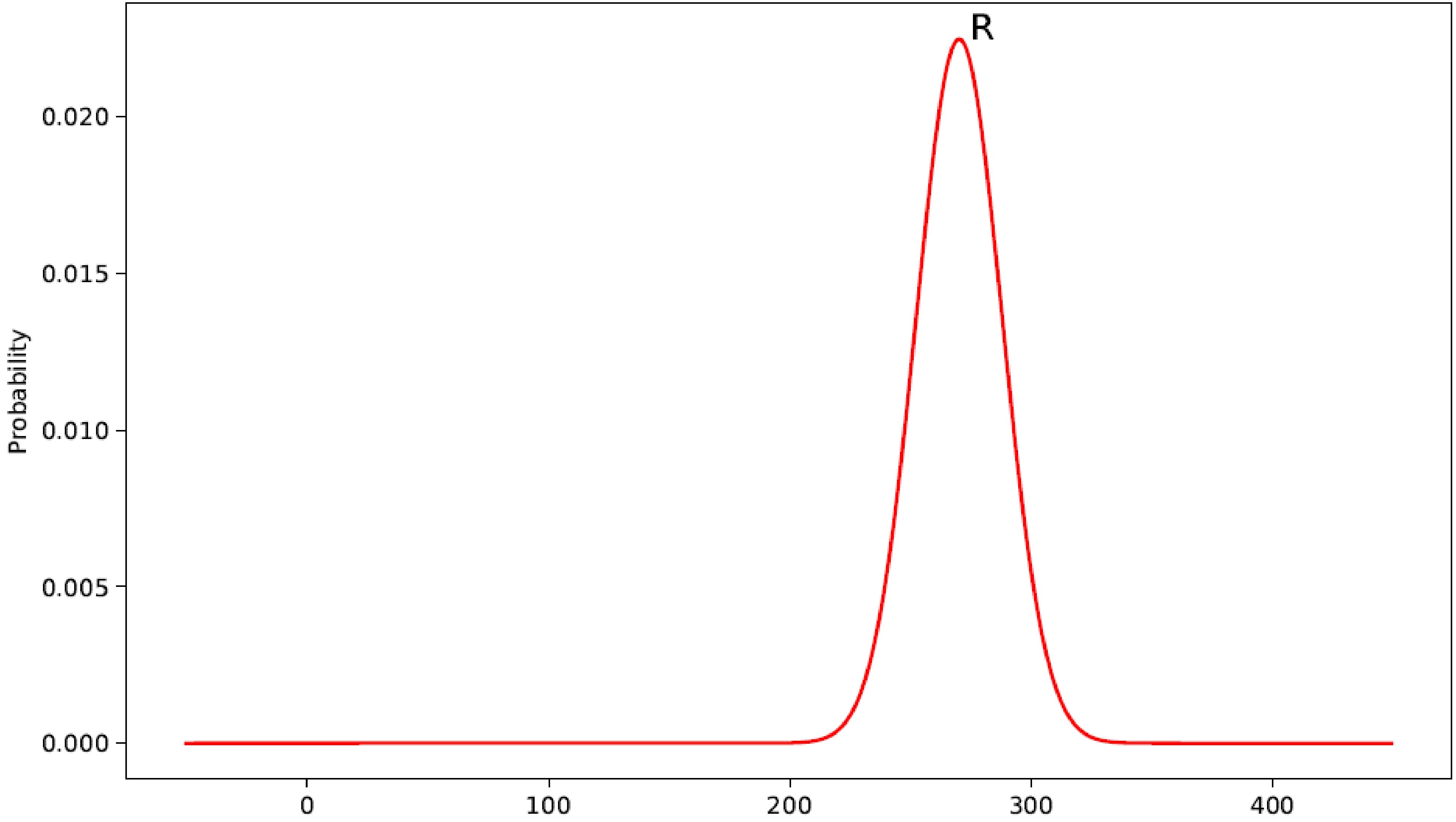
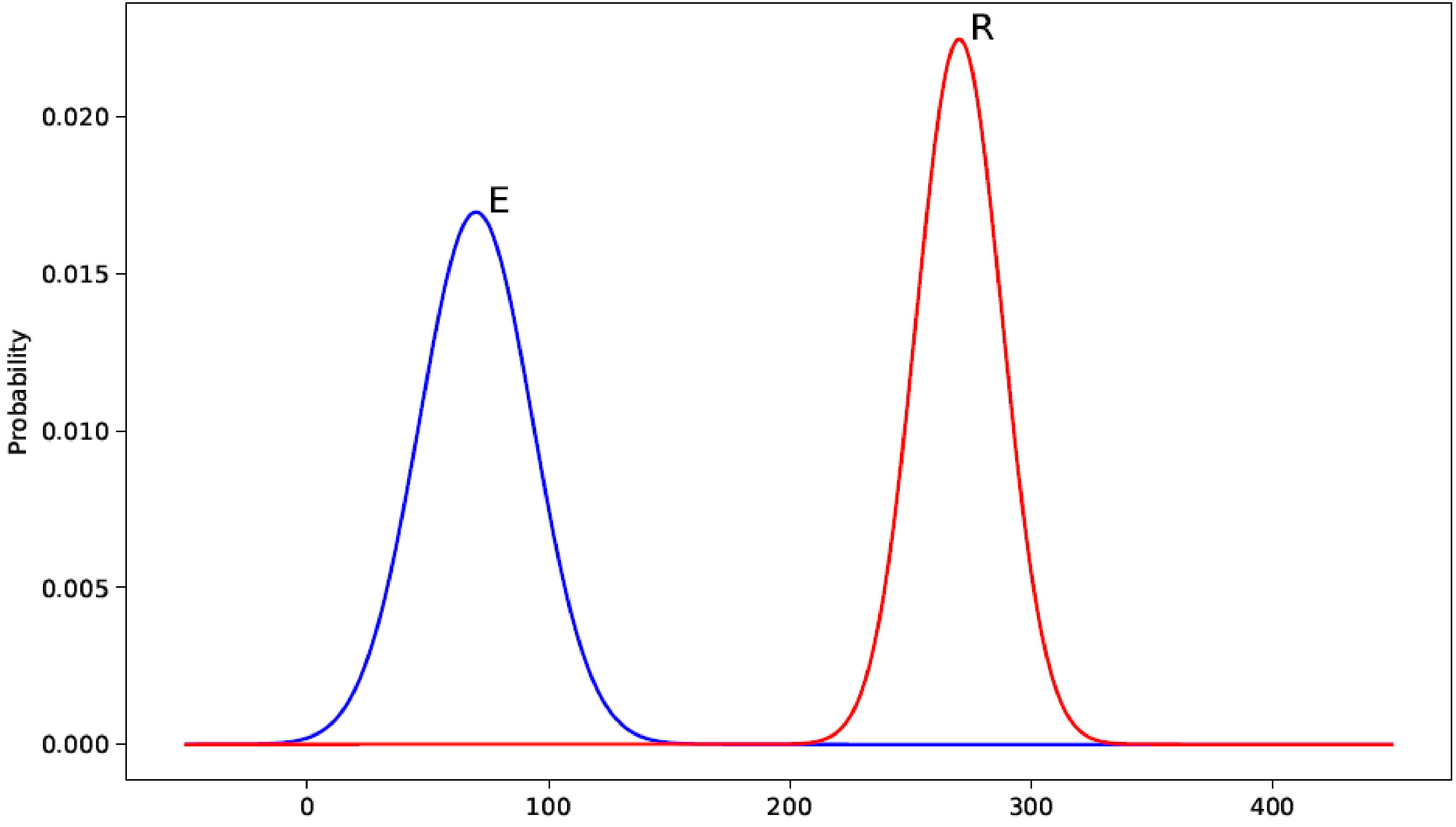
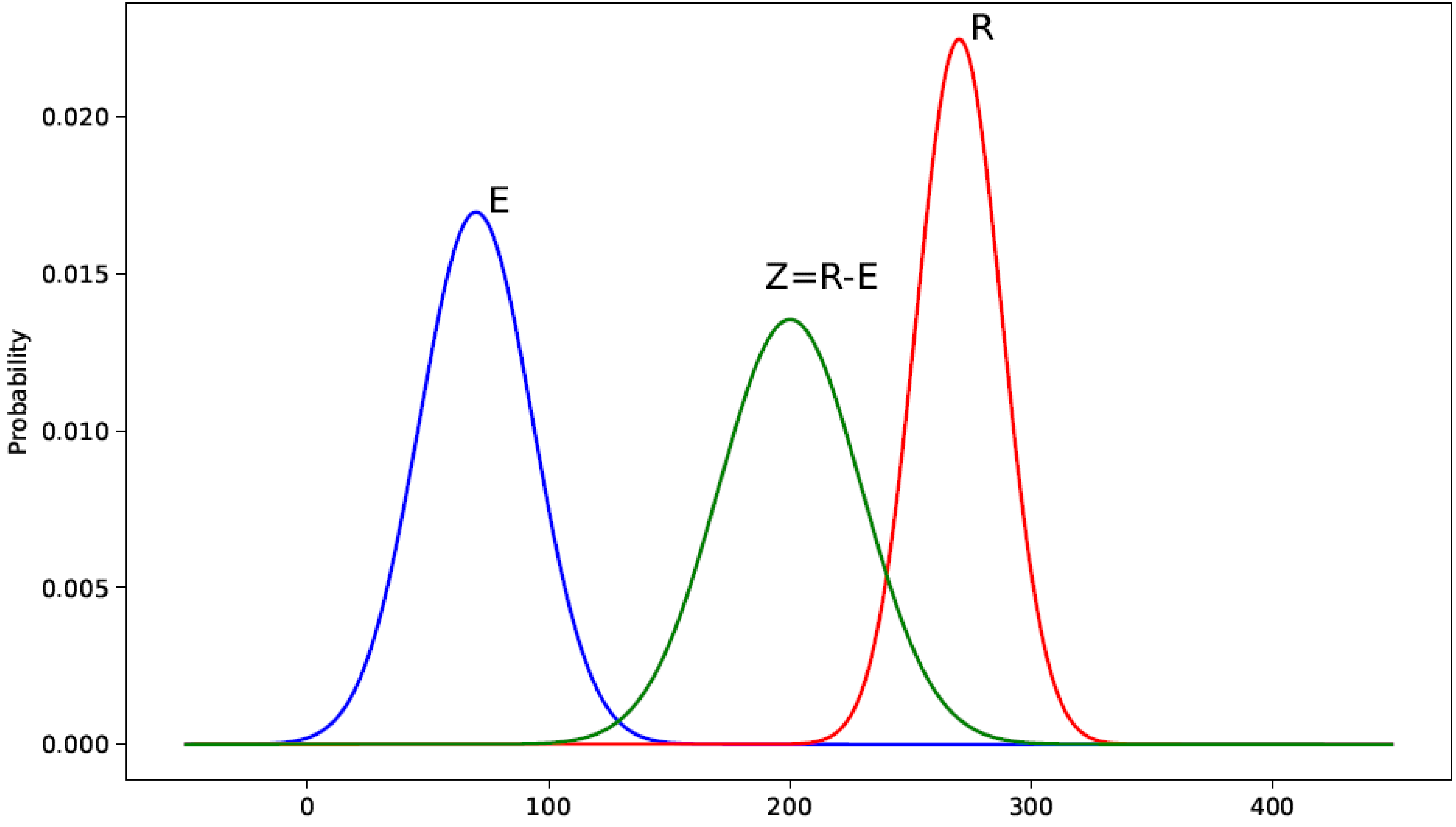
How is reliability index β determined?



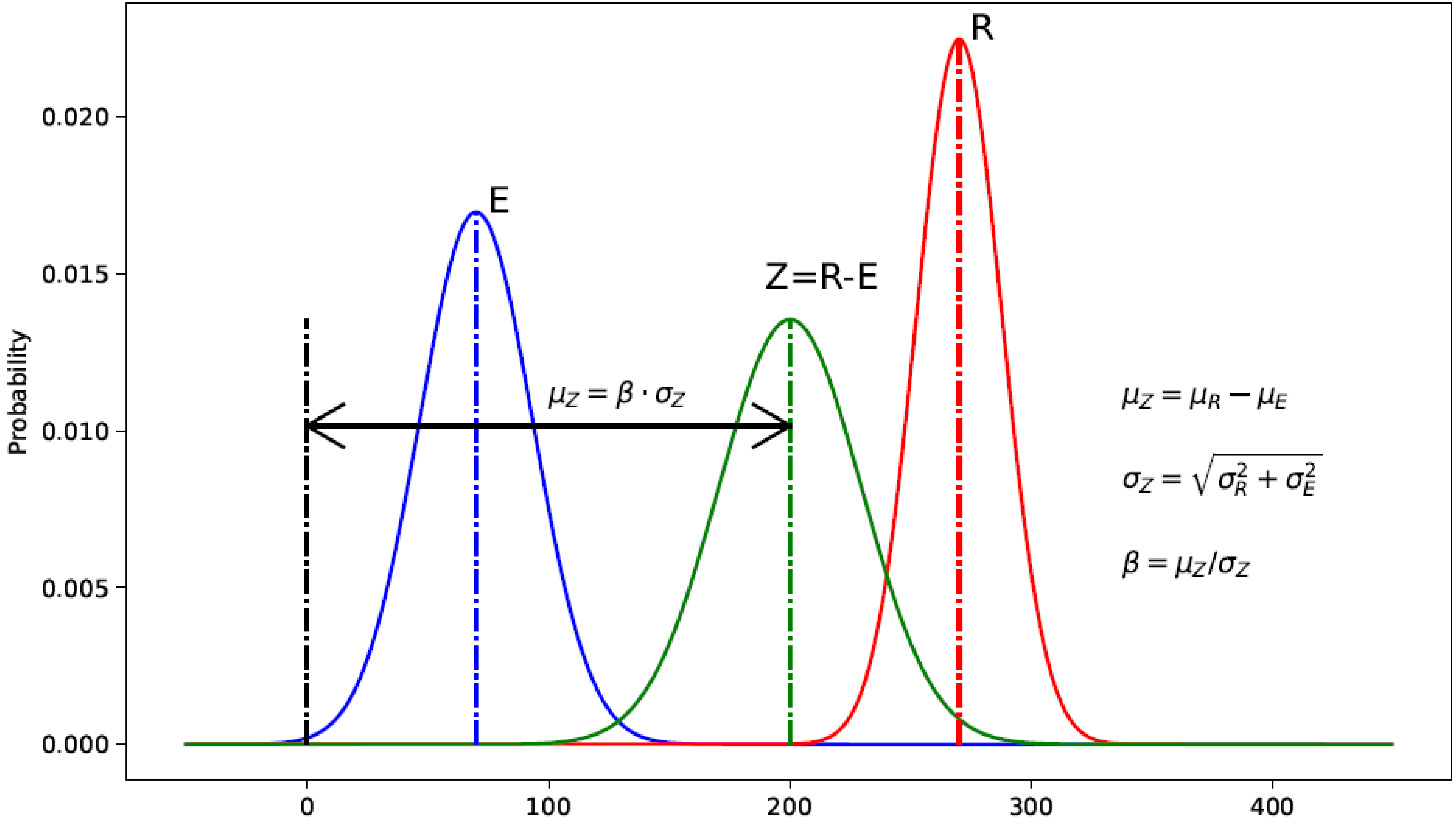
How is reliability index β determined?



How is reliability index β determined?



How is reliability index β determined?



https://gitlab.tudelft.nl/roelschipper/ciem5000/-/blob/main/Z_curve_highgamma_uc0.81_beta6.8.ipynb

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Table 2.5: Consequence classes for **buildings** Mind that National Annexes for CEN member states frequently define different combination values from the ones presented in these tables (draft prNEN-EN-1990 2021)

consequence class	description of consequence	examples for buildings
CC3	higher	buildings where many people assemble, e.g. grandstands, concert and exposition halls, tall buildings, large public buildings
CC2	normal	buildings where people normally enter, e.g. residential and office buildings, public buildings, industrial buildings with $\geq$3 layers
CC1	lower	buildings where people do not normally enter, e.g. agricultural buildings, storage buildings, industrial buildings with 1 or 2 layers

Table 2.6: Consequence classes for **bridges** (draft prNEN-EN-1990 2021)

consequence class	description of consequence	examples for bridges
CC3b	higher (upper risk group)	Where an increased level of reliability is required, when specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties
CC3a	higher (lower risk group)	Railway bridges on main railway lines, bridges over main railway lines, bridges over and under major roads
CC2	normal	Bridges not in other consequence classes
CC1	lower	Short span bridges on local roads with little traffic (provided they do not span over main railway lines or major roads)

Table 2.4: Consequence classes, qualification of consequences, reliability index β, probability of failure P_f, and consequence factor K_F in the Ultimate Limit State (prNEN-EN-1990 2021)

class	consequences	indicative qualification of consequences: loss of human life or personal injury	indicative qualification of consequences: economic, social or environmental consequences	50-year reference period: β_{50}	50-year reference period: $P_{f;50}$
CC4	highest	extreme	huge		
CC3	higher	high	very great	4.3	$\sim 10^{-5}$
CC2	normal	medium	considerable	3.8	$\sim 10^{-4}$
CC1	lower	low	small	3.3	$\sim 10^{-3}$
CC0	lowest	very low	insignificant		

Table 2.4: Consequence classes, qualification of consequences, reliability index β, probability of failure P_f, and consequence factor K_F in the Ultimate Limit State (prNEN-EN-1990 2021)

class	consequences	indicative qualification of consequences		1-year reference period	50-year reference period	
		loss of human life or personal injury	economic, social or environmental consequences	β_1	β_{50}	$P_{f;50}$
CC4	highest	extreme	huge			
CC3	higher	high	very great	5.2	4.3	$\sim 10^{-5}$
CC2	normal	medium	considerable	4.7	3.8	$\sim 10^{-4}$
CC1	lower	low	small	4.2	3.3	$\sim 10^{-3}$
CC0	lowest	very low	insignificant			

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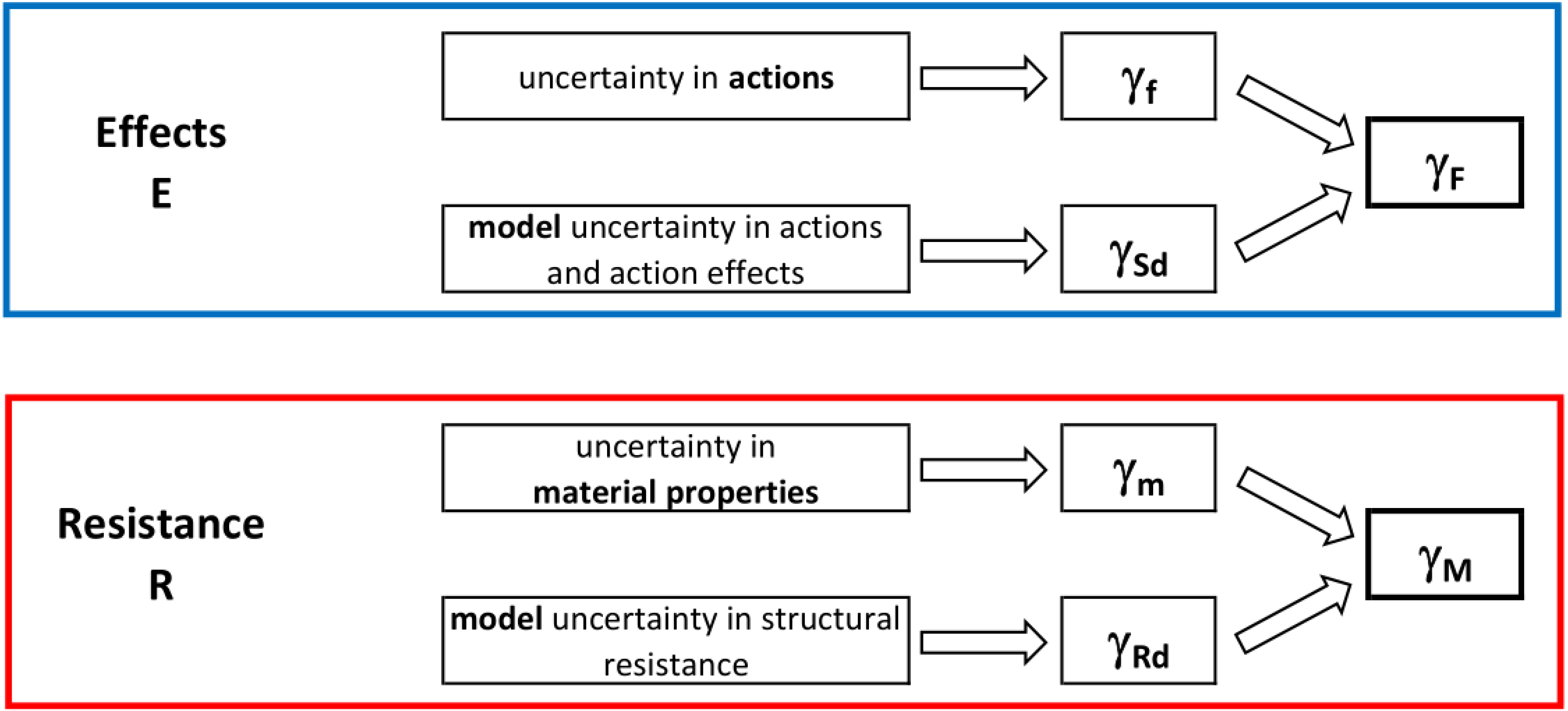
Effects
E
uncertainty in **actions**
model uncertainty in actions and action effects
γ_f
γ_{Sd}
γ_F
Resistance
R
uncertainty in **material properties**
model uncertainty in structural resistance
γ_m
γ_{Rd}
γ_M

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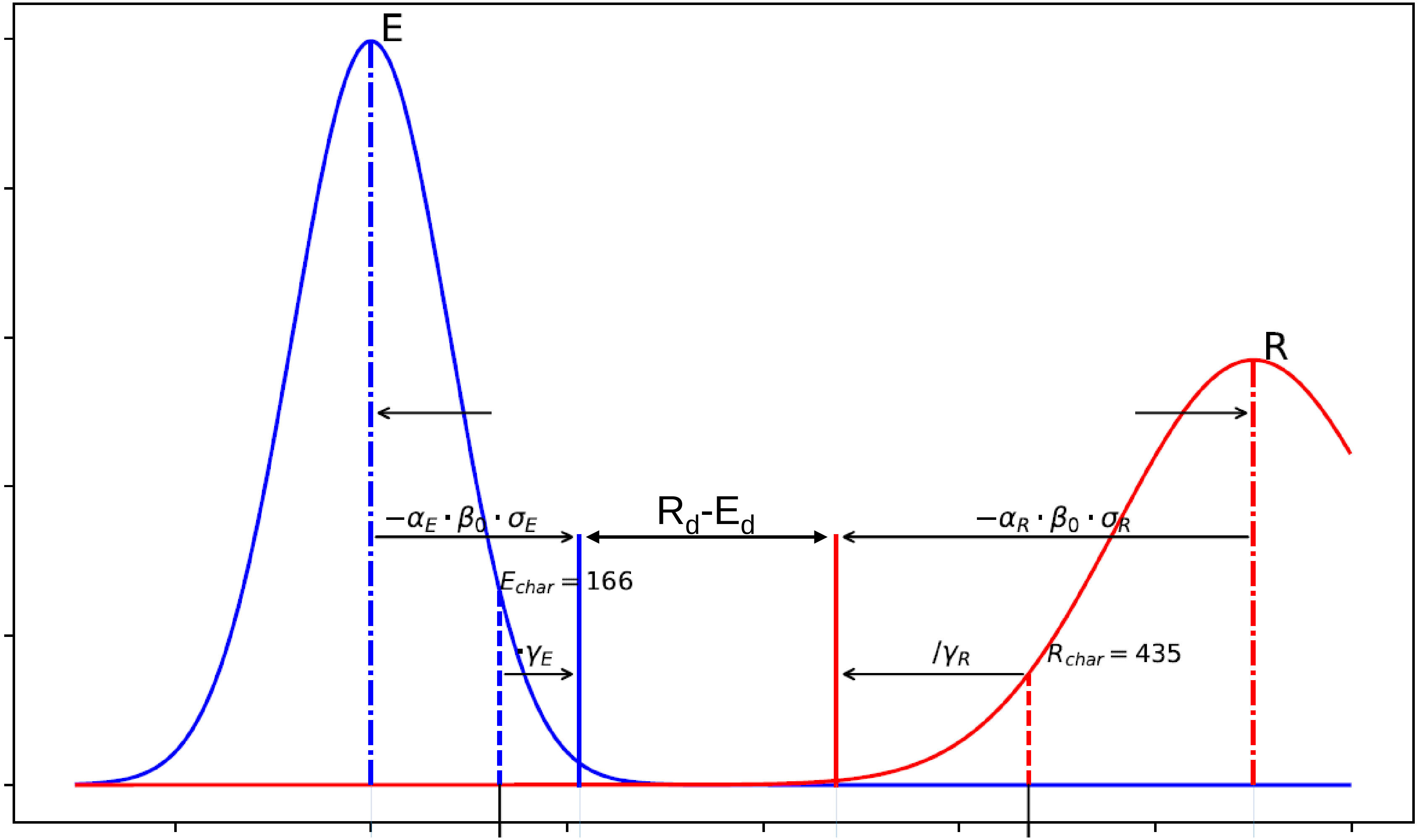
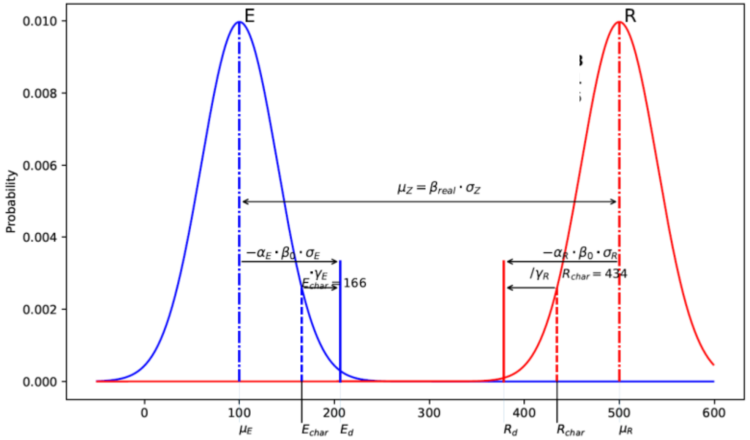
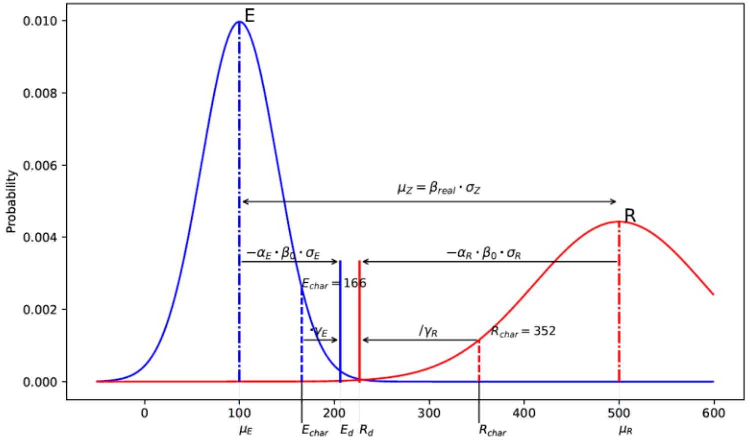
partial factors



https://gitlab.tudelft.nl/roelschipper/ciem5000/-/blob/main/partialfactors.ipynb

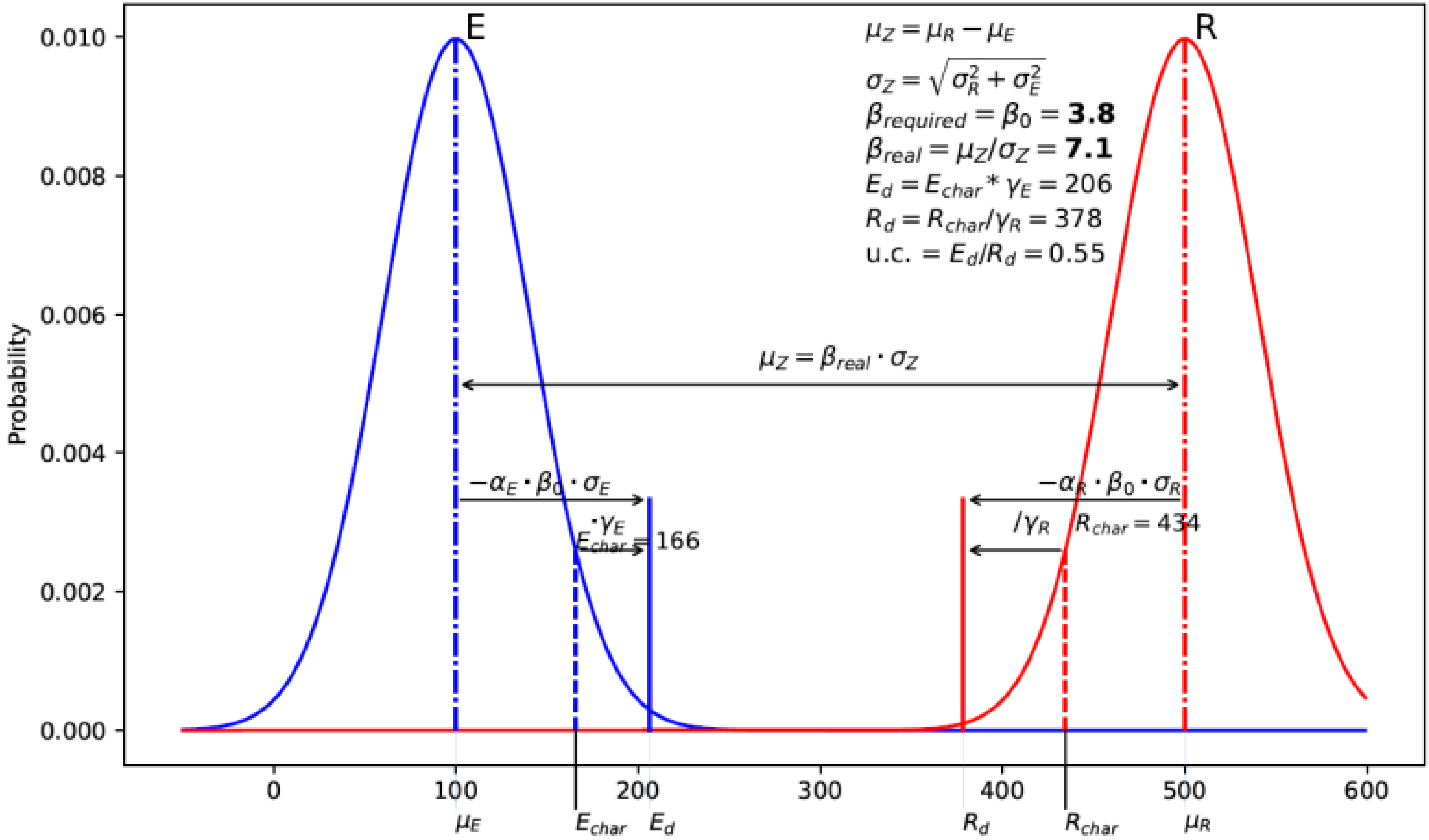
effect of shift of σ_R (SD R)
μ_R remains constant

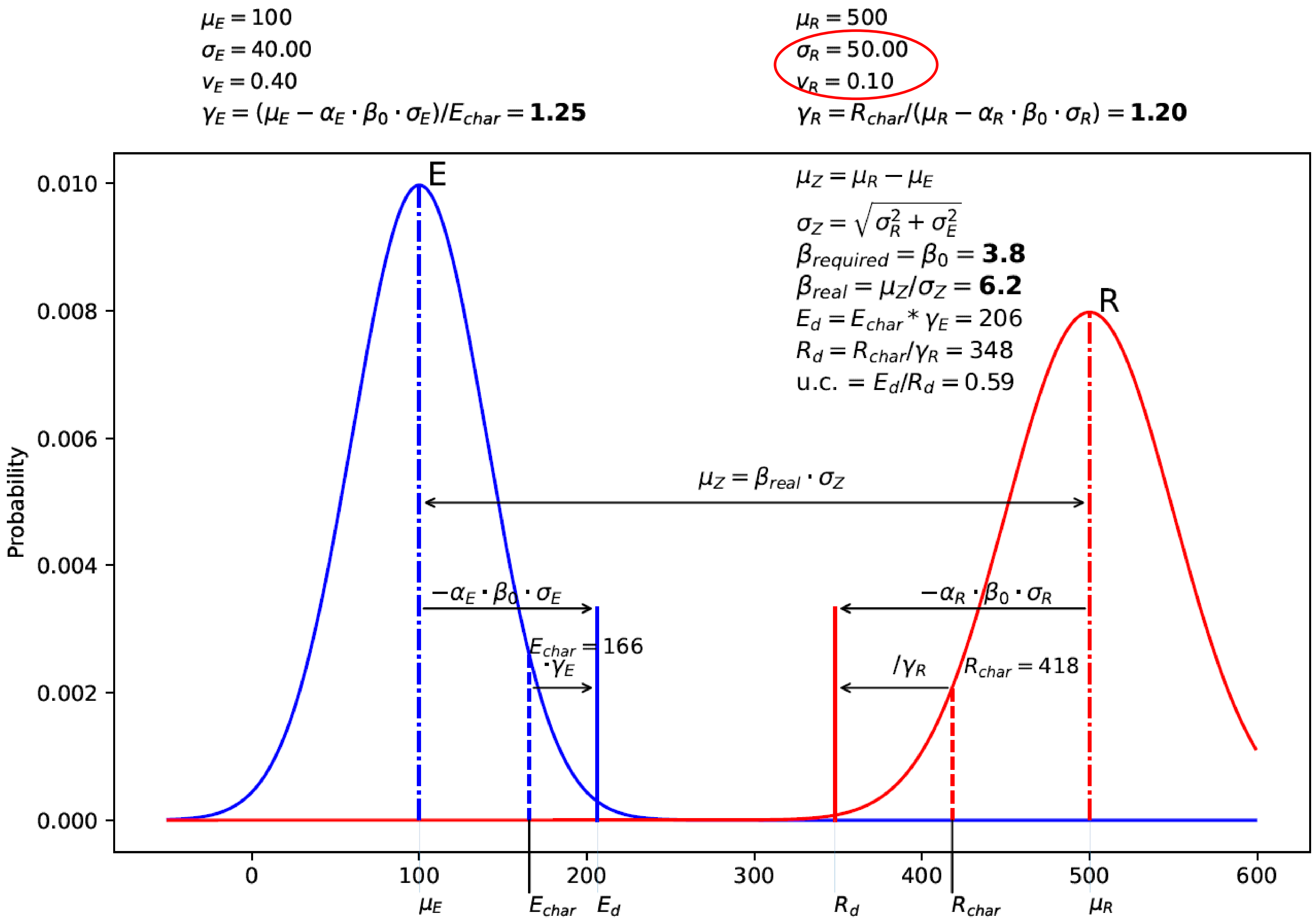




$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$
$\sigma_R = 40.00$
$v_R = 0.08$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.15}$





$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$
$\mu_R = 500$
$\sigma_R = 50.00$
$v_R = 0.10$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.20}$
E
R
$\mu_Z = \mu_R - \mu_E$
$\sigma_Z = \sqrt{\sigma_R^2 + \sigma_E^2}$
$\beta_{required} = \beta_0 = \mathbf{3.8}$
$\beta_{real} = \mu_Z/\sigma_Z = \mathbf{6.2}$
$E_d = E_{char} * \gamma_E = 206$
$R_d = R_{char}/\gamma_R = 348$
$\text{u.c.} = E_d/R_d = 0.59$
$\mu_Z = \beta_{real} \cdot \sigma_Z$
$-\alpha_E \cdot \beta_0 \cdot \sigma_E$
$-\alpha_R \cdot \beta_0 \cdot \sigma_R$
$E_{char} = 166$
$\cdot \gamma_E$
$/\gamma_R$
$R_{char} = 418$
Probability
0.010
0.008
0.006
0.004
0.002
0.000
0
100
200
300
400
500
600
μ_E
E_{char}
E_d
R_d
R_{char}
μ_R

$\mu_E = 100$

$\sigma_E = 40.00$

$v_E = 0.40$

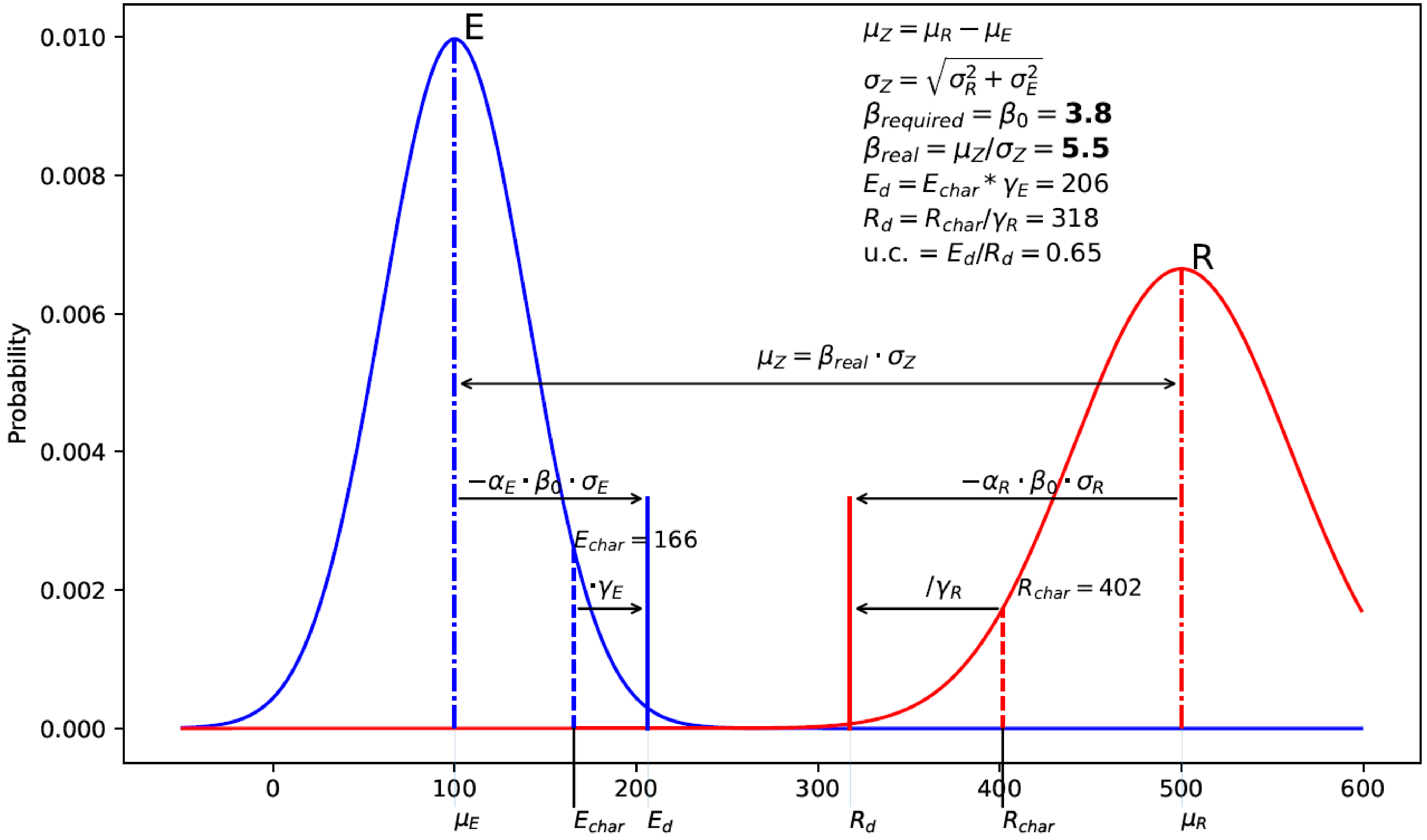
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$

$\sigma_R = 60.00$

$v_R = 0.12$

$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.26}$



$\mu_E = 100$

$\sigma_E = 40.00$

$v_E = 0.40$

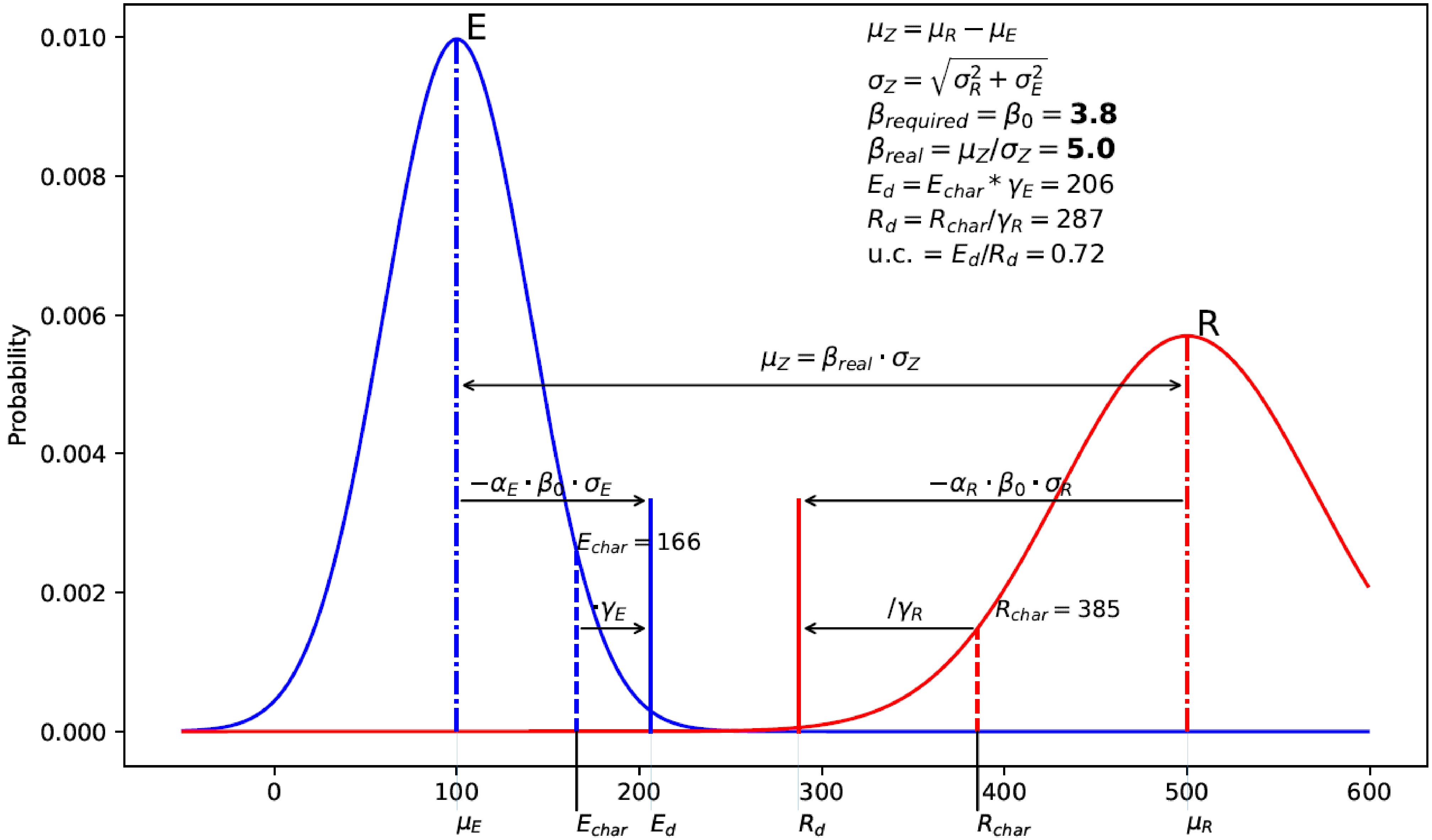
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$

$\sigma_R = 70.00$

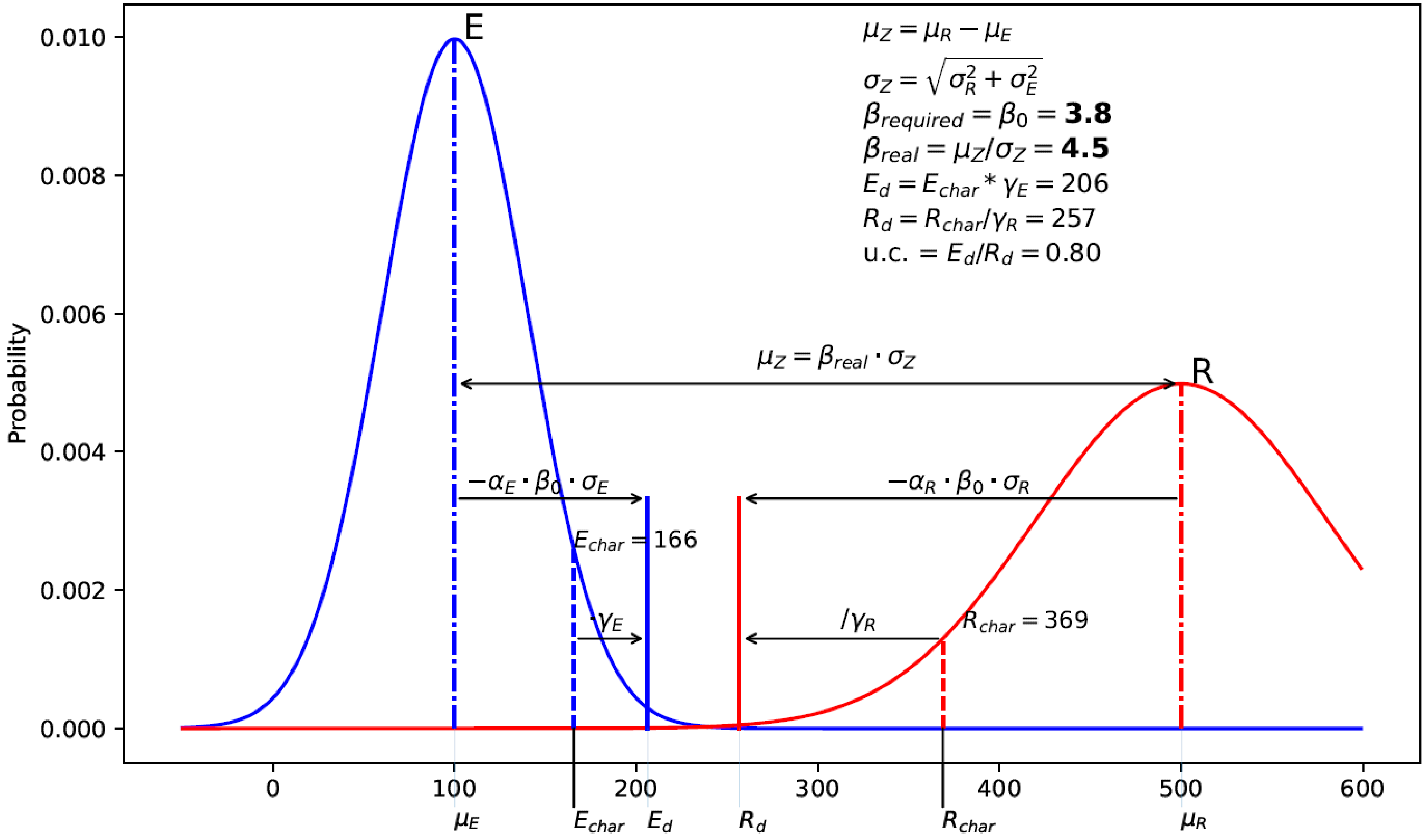
$v_R = 0.14$

$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.34}$



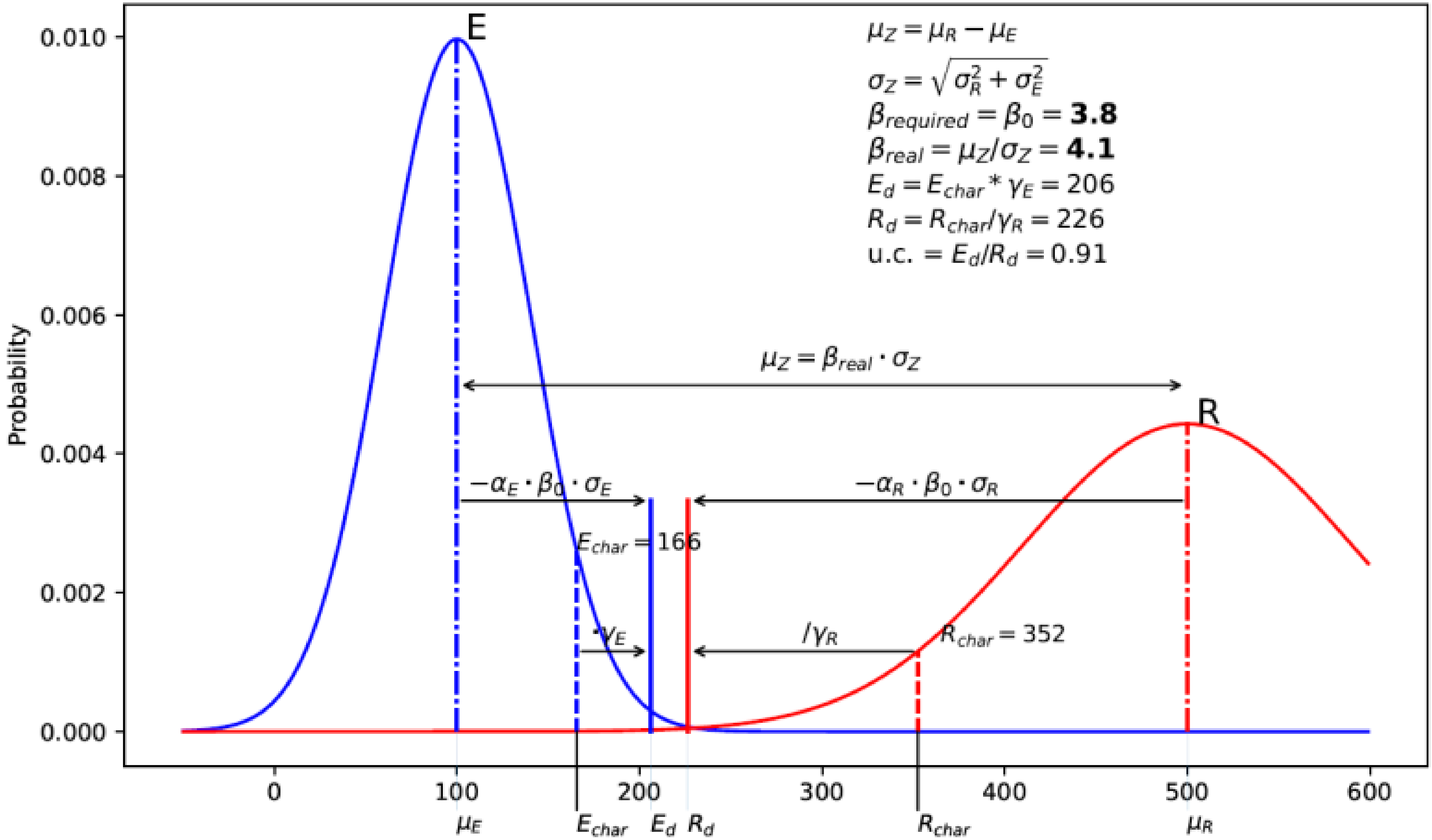
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$
$\sigma_R = 80.00$
$v_R = 0.16$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.44}$

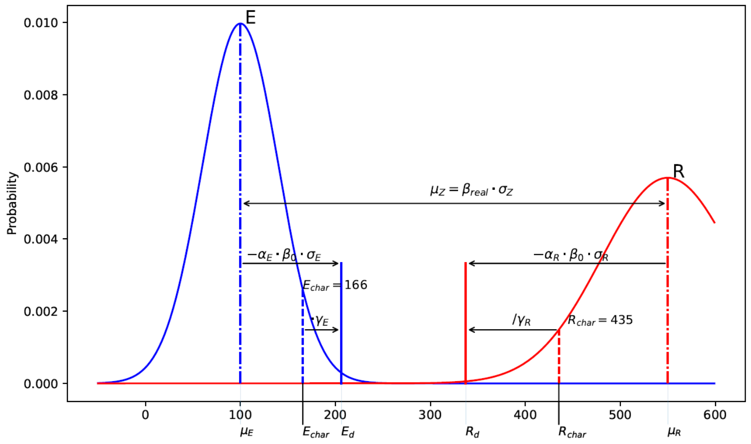


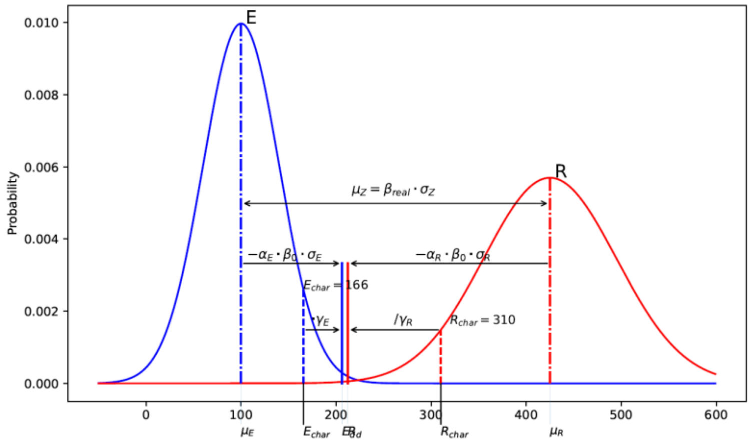
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$
$\sigma_R = 90.00$
$v_R = 0.18$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.56}$



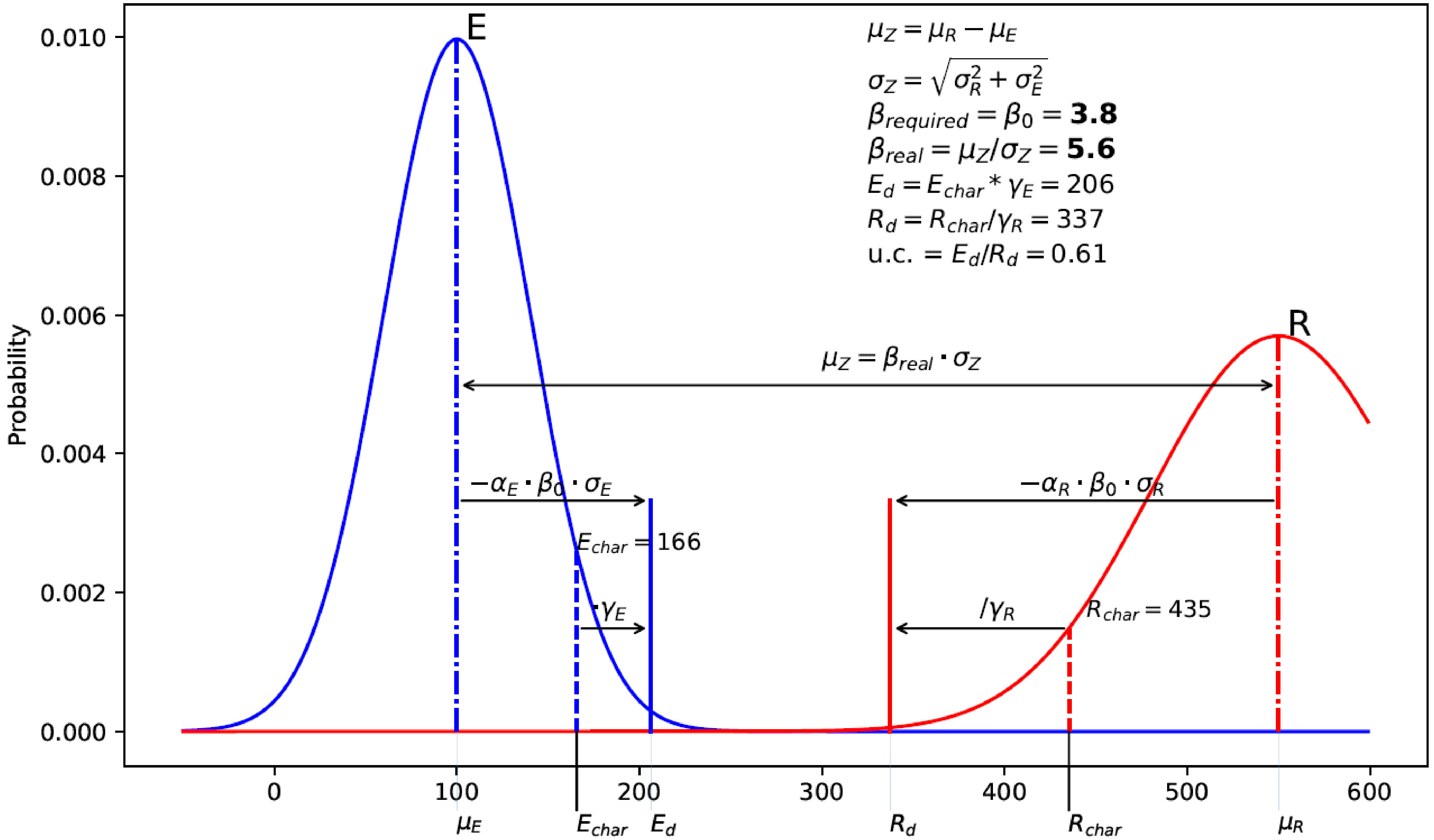
effect of shift of μ_R (mean R)
σ_R remains constant





$$\mu_E = 100$$
$$\sigma_E = 40.00$$
$$v_E = 0.40$$
$$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$$

$$\mu_R = 550$$
$$\sigma_R = 70.00$$
$$v_R = 0.13$$
$$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.29}$$



$\mu_E = 100$

$\sigma_E = 40.00$

$v_E = 0.40$

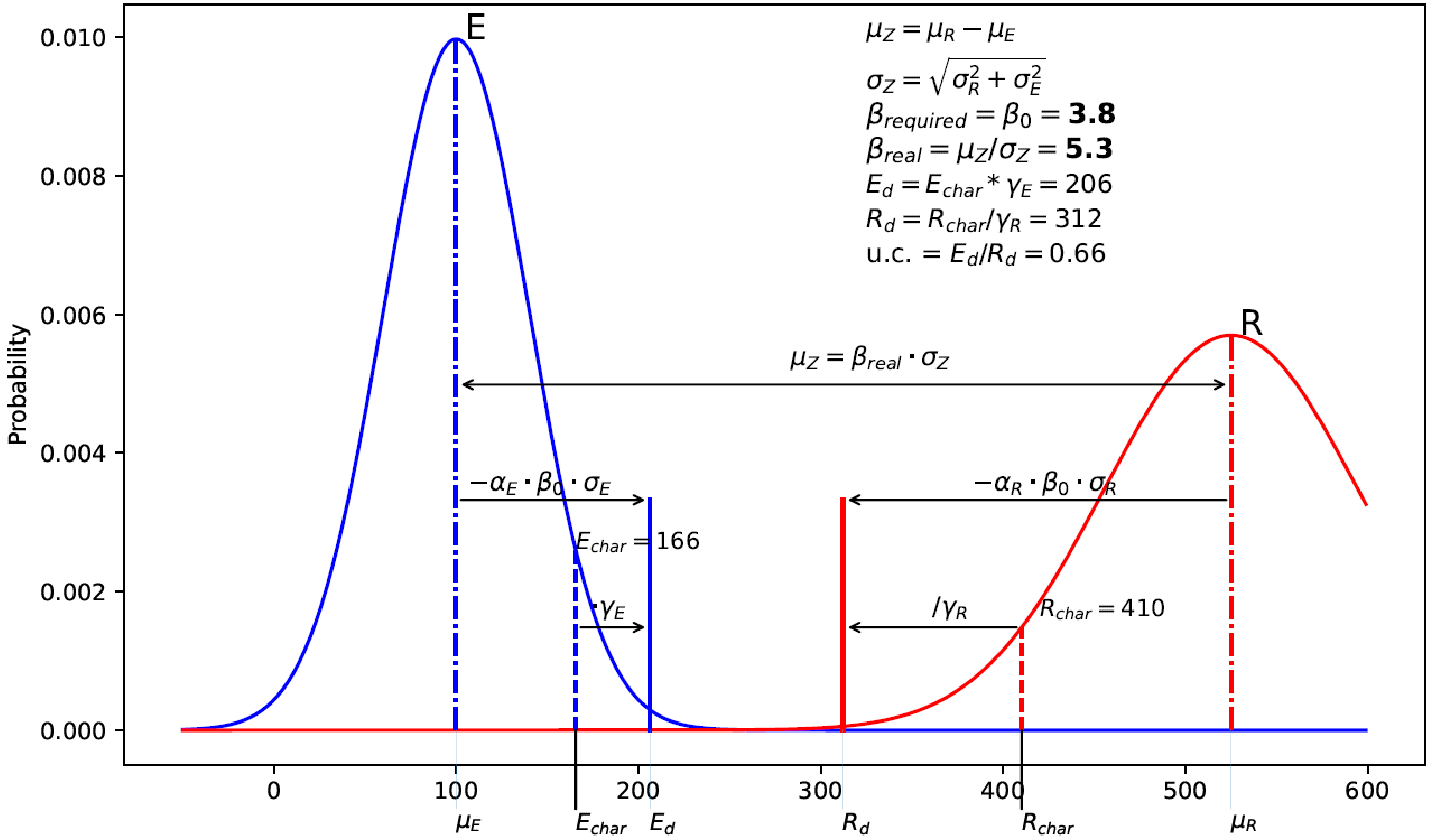
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 525$

$\sigma_R = 70.00$

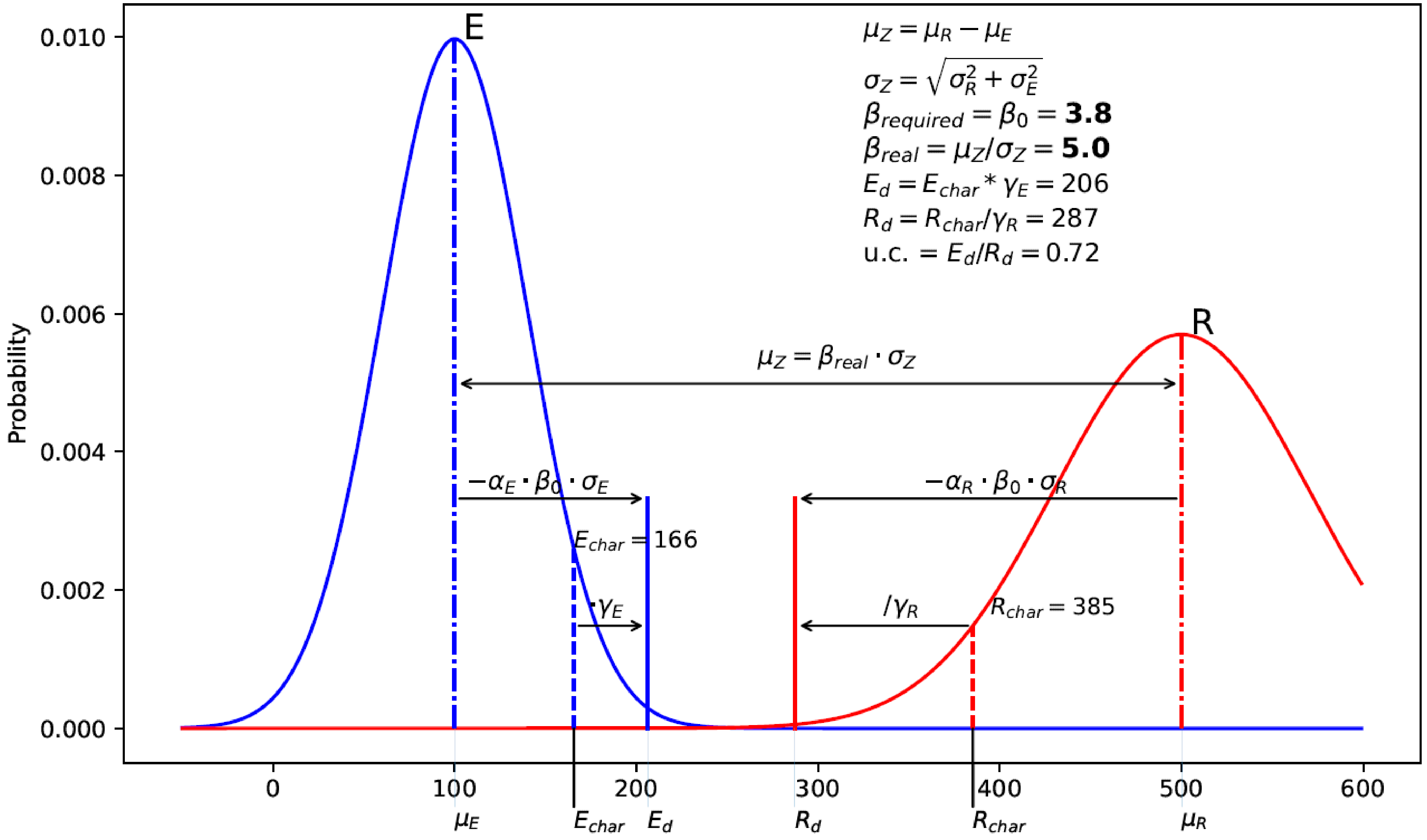
$v_R = 0.13$

$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.31}$



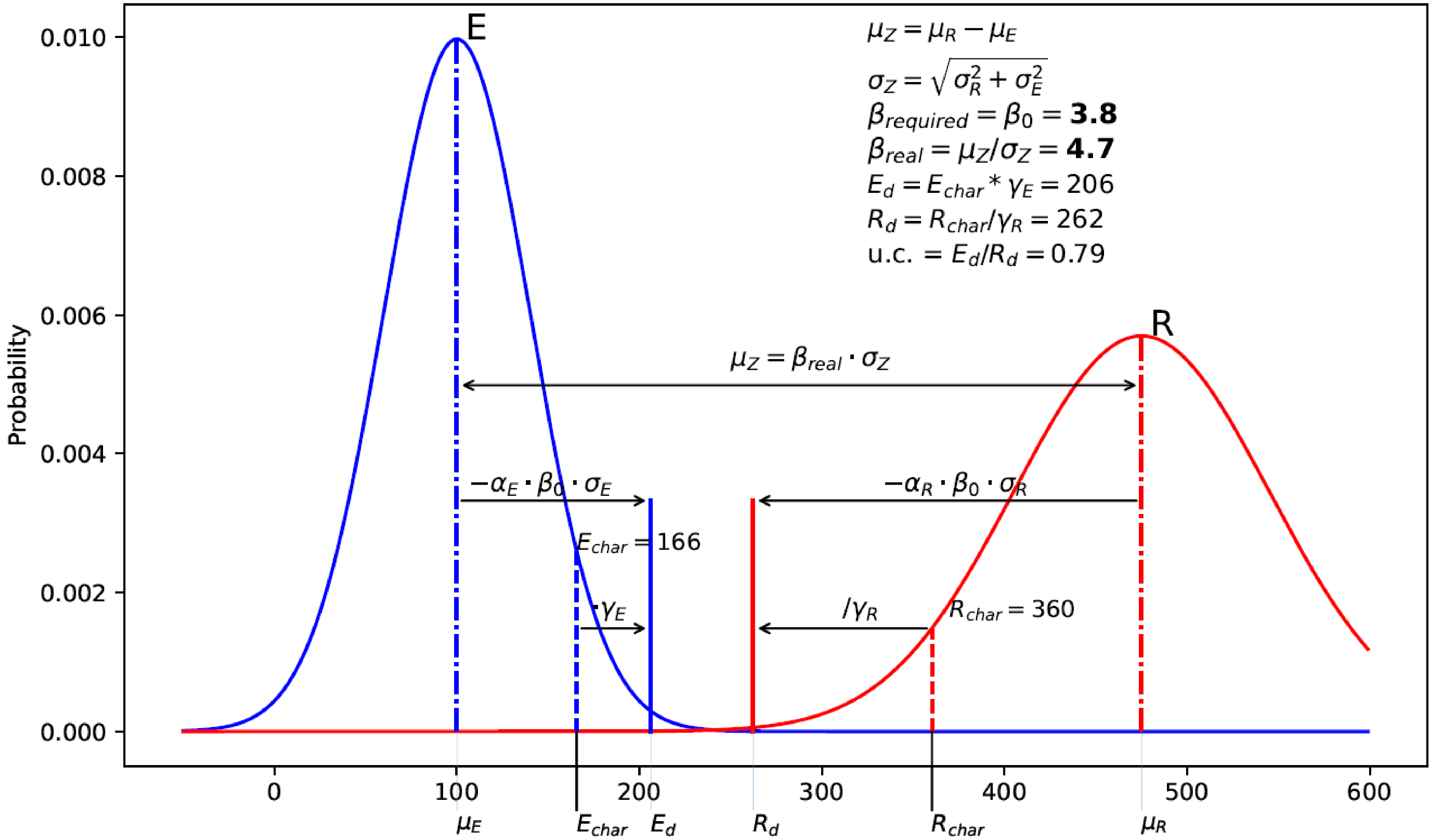
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$
$\sigma_R = 70.00$
$v_R = 0.14$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.34}$



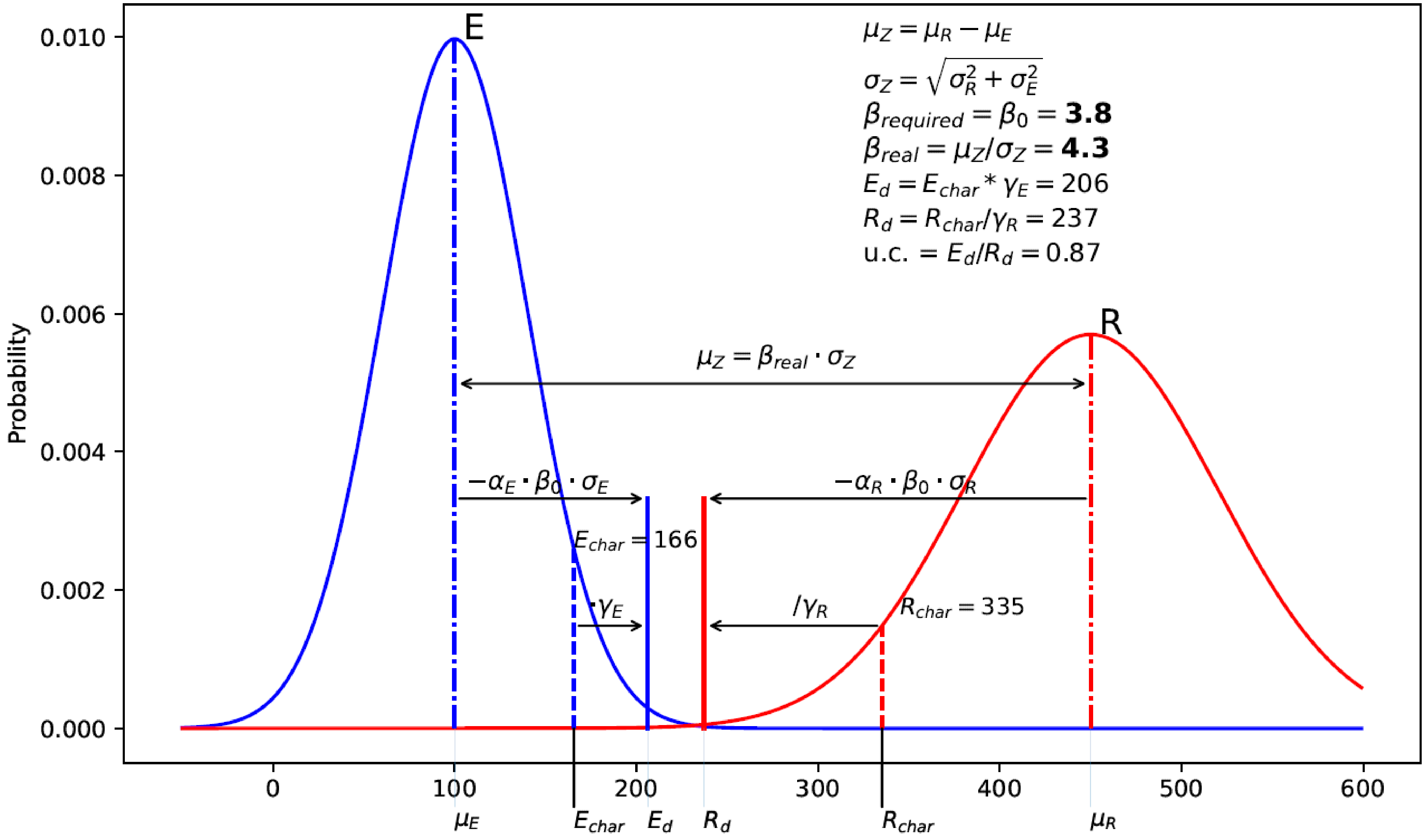
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

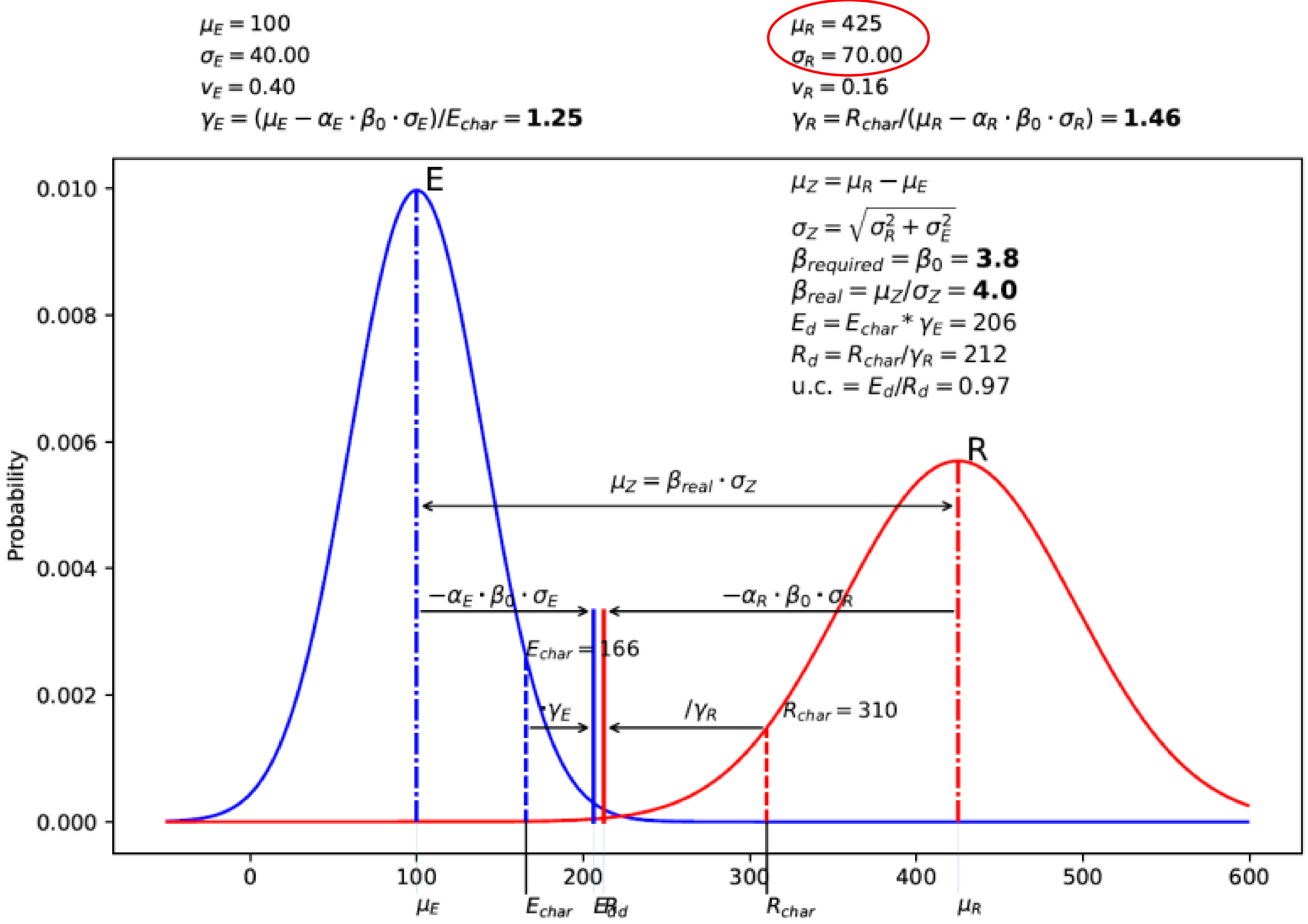
$\mu_R = 475$
$\sigma_R = 70.00$
$v_R = 0.15$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.37}$



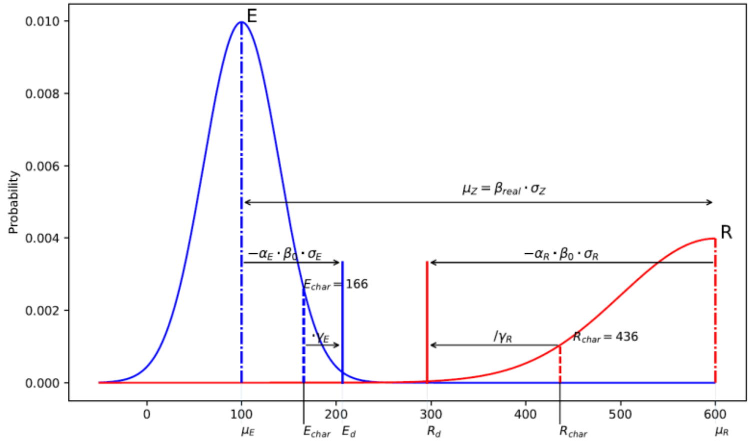
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

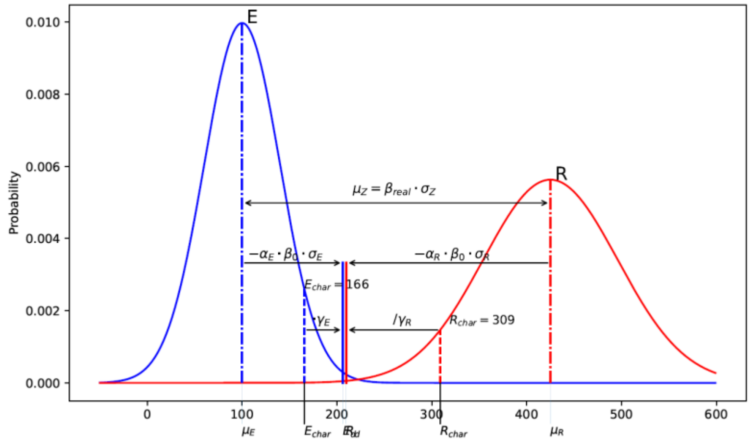
$\mu_R = 450$
$\sigma_R = 70.00$
$v_R = 0.16$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.41}$




μE = 100
σE = 40.00
vE = 0.40
γE = (μE − αE · β0 · σE)/Echar = 1.25
μR = 425
σR = 70.00
vR = 0.16
γR = Rchar/(μR − αR · β0 · σR) = 1.46
μZ = μR − μE
σZ = √(σR² + σE²)
βrequired = β0 = 3.8
βreal = μZ/σZ = 4.0
Ed = Echar * γE = 206
Rd = Rchar/γR = 212
u.c. = Ed/Rd = 0.97
E
R
μZ = βreal · σZ
−αE · β0 · σE
−αR · β0 · σR
Echar = 166
·γE
/γR
Rchar = 310
Probability
0.010
0.008
0.006
0.004
0.002
0.000
0
100
200
300
400
500
600
μE
Echar
Ed
Rd
Rchar
μR

effect of shift of μ_R (mean R) COV_R remains constant





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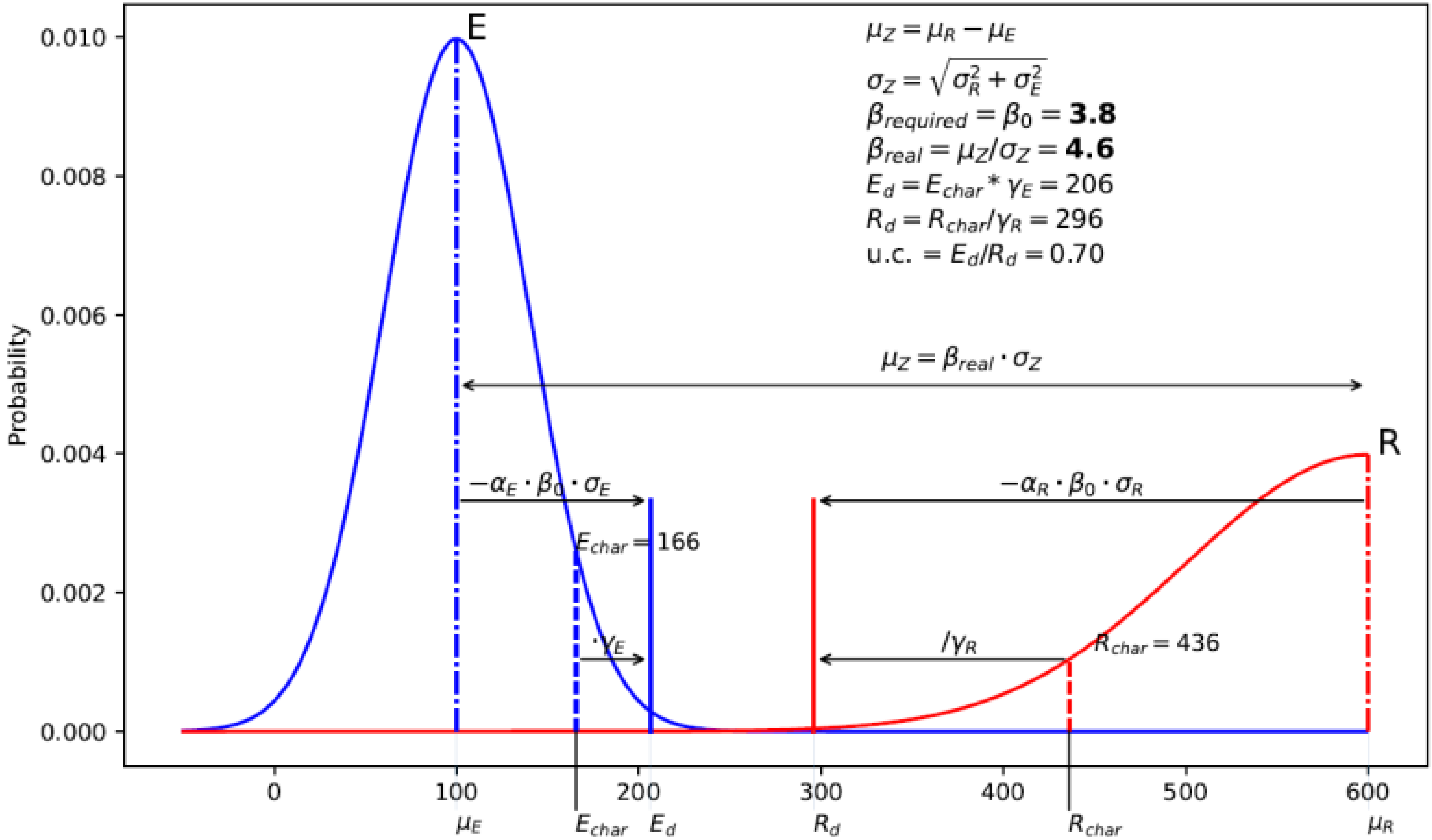
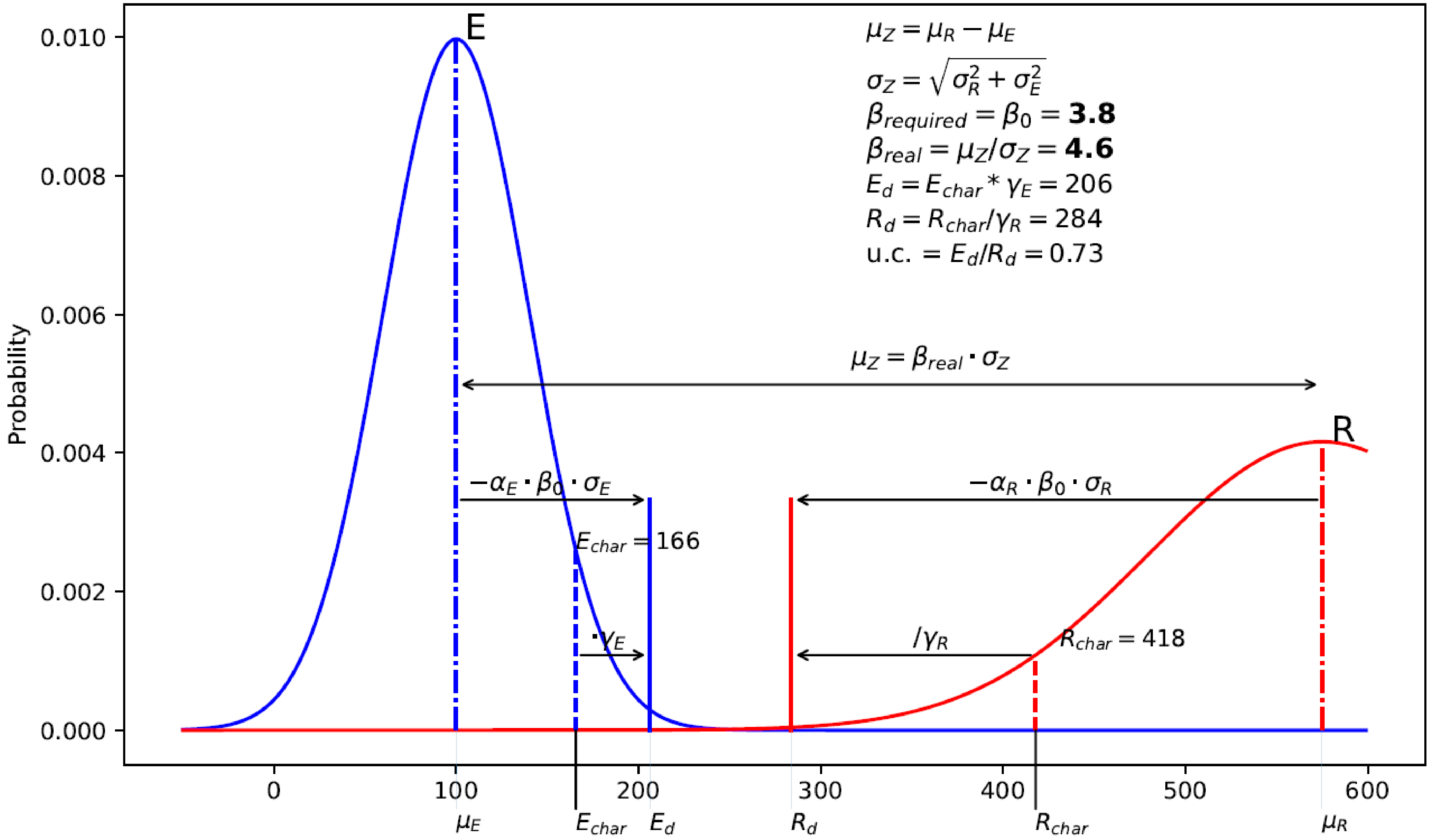
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 600$
$\sigma_R = 100.00$
$v_R = 0.17$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 575$
$\sigma_R = 95.83$
$v_R = 0.17$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



$\mu_E = 100$

$\sigma_E = 40.00$

$v_E = 0.40$

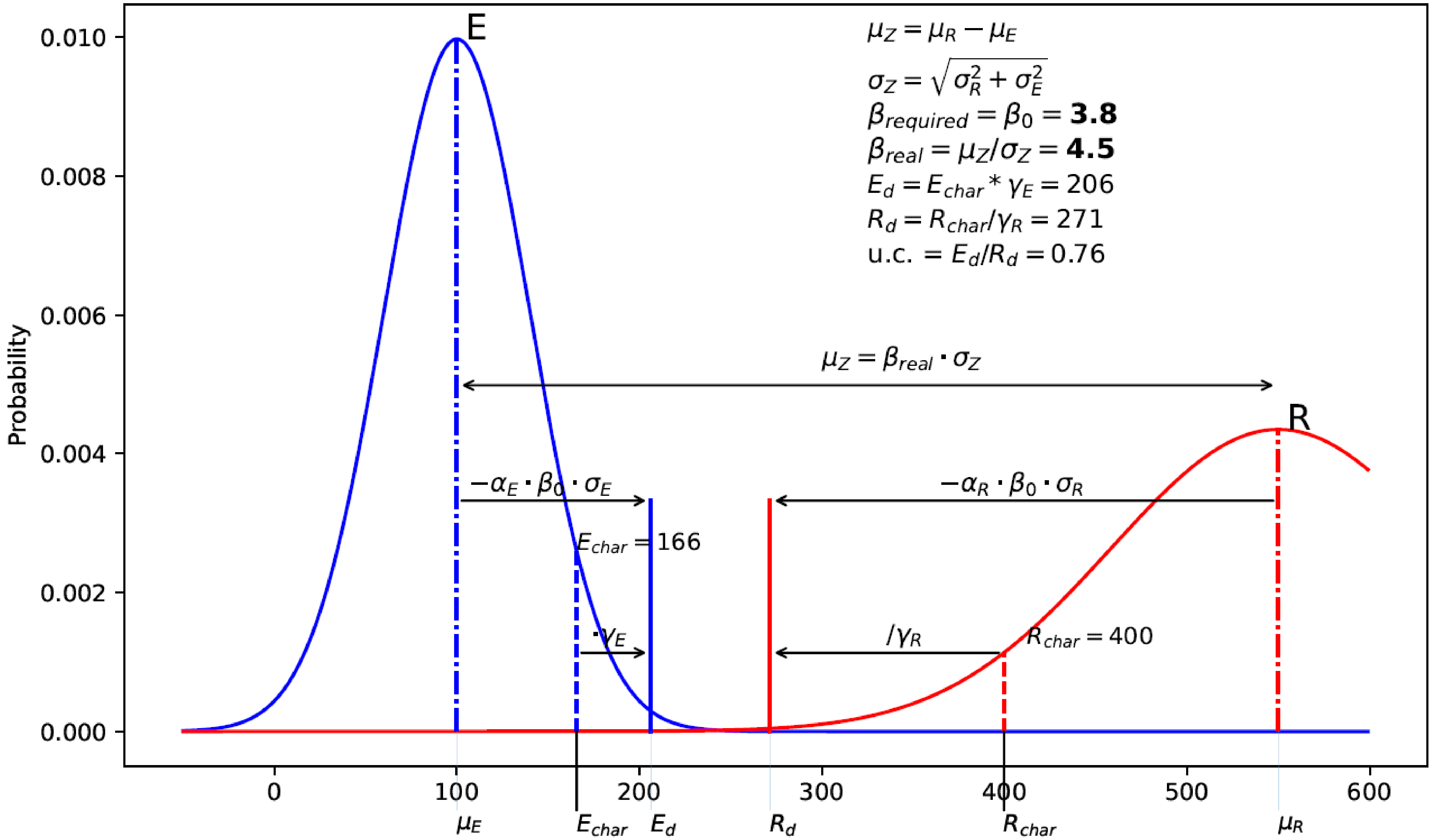
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 550$

$\sigma_R = 91.67$

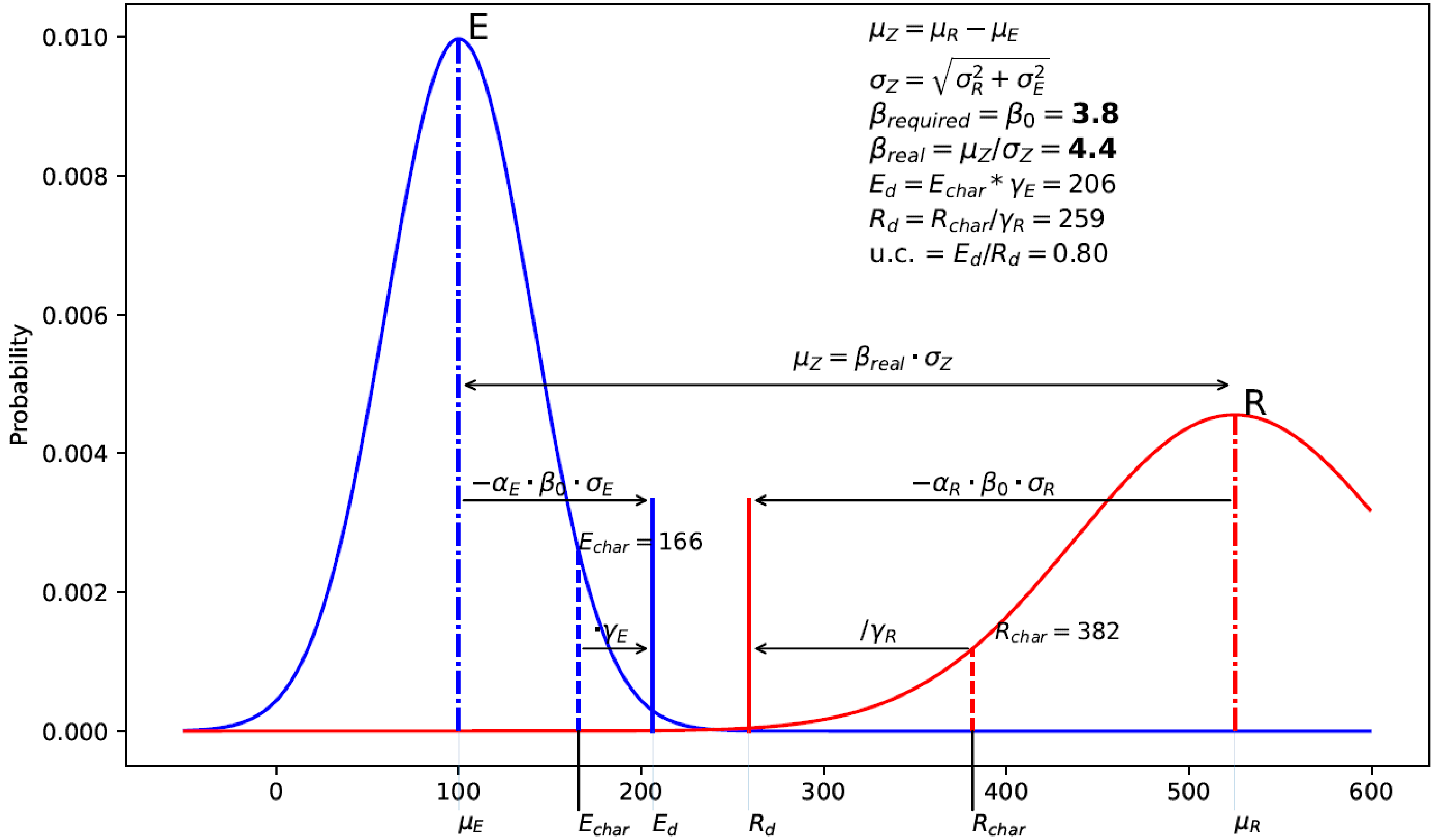
$v_R = 0.17$

$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



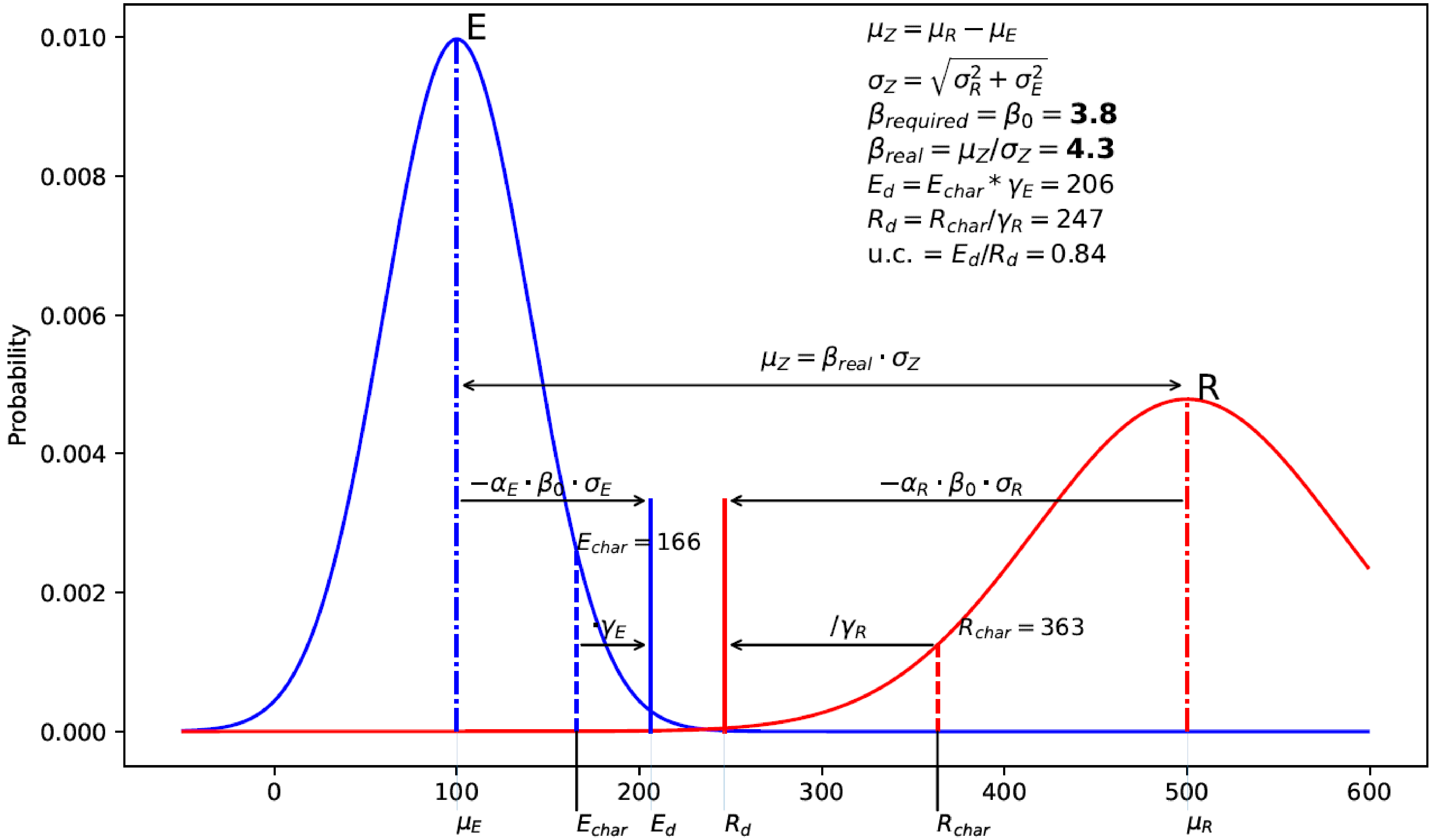
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 525$
$\sigma_R = 87.50$
$v_R = 0.17$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 500$
$\sigma_R = 83.33$
$v_R = 0.17$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



$\mu_E = 100$

$\sigma_E = 40.00$

$v_E = 0.40$

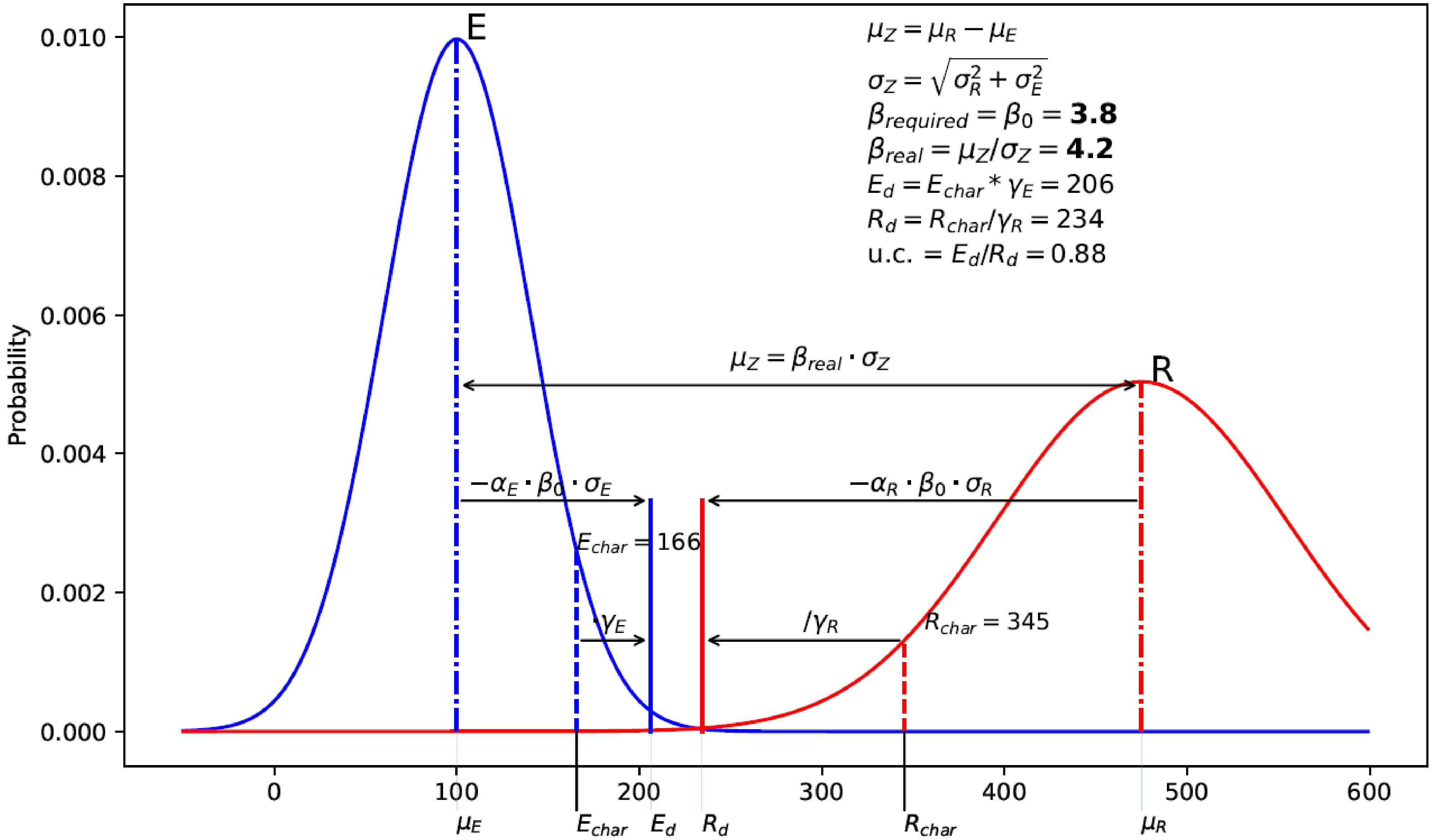
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 475$

$\sigma_R = 79.17$

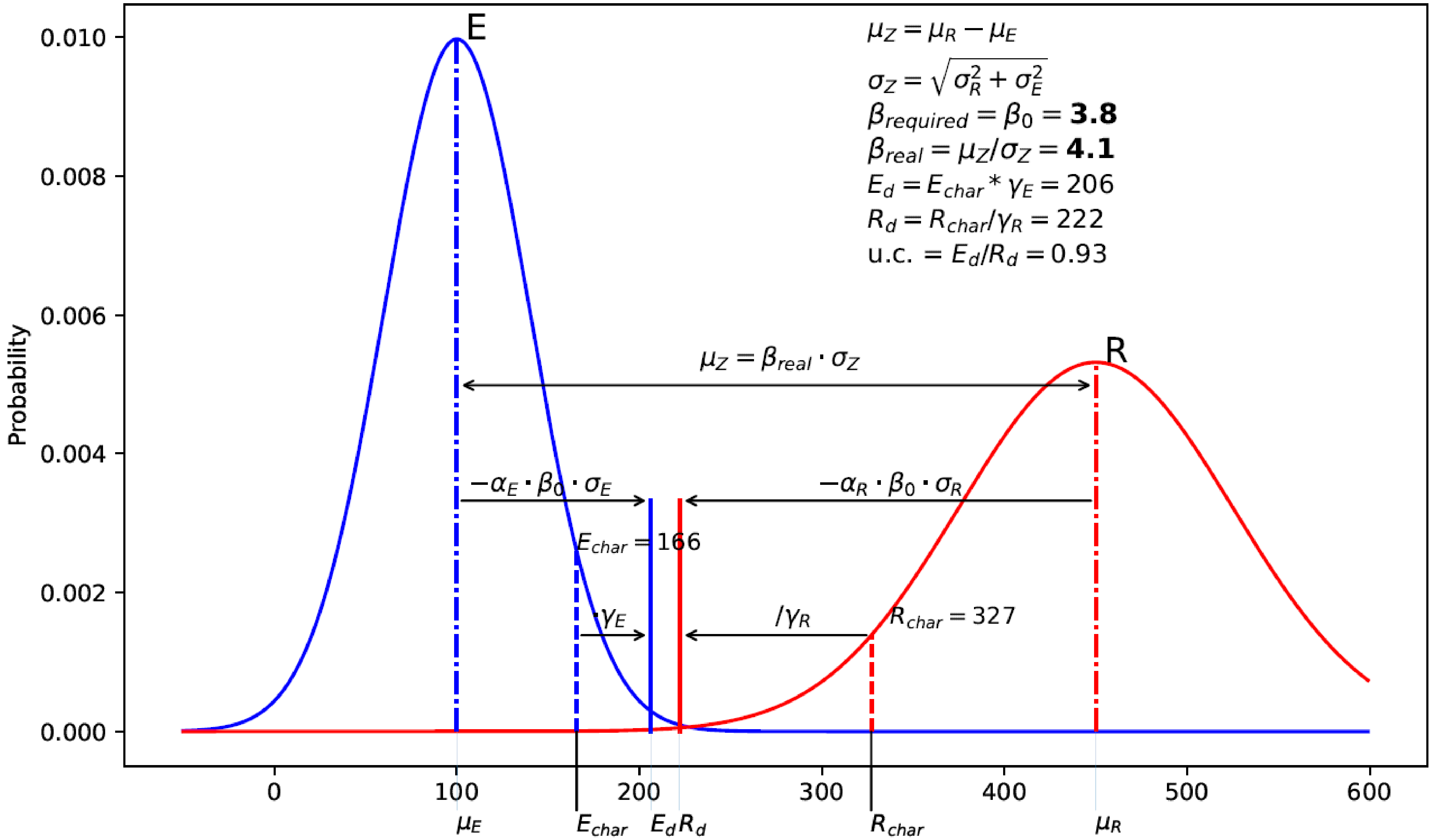
$v_R = 0.17$

$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



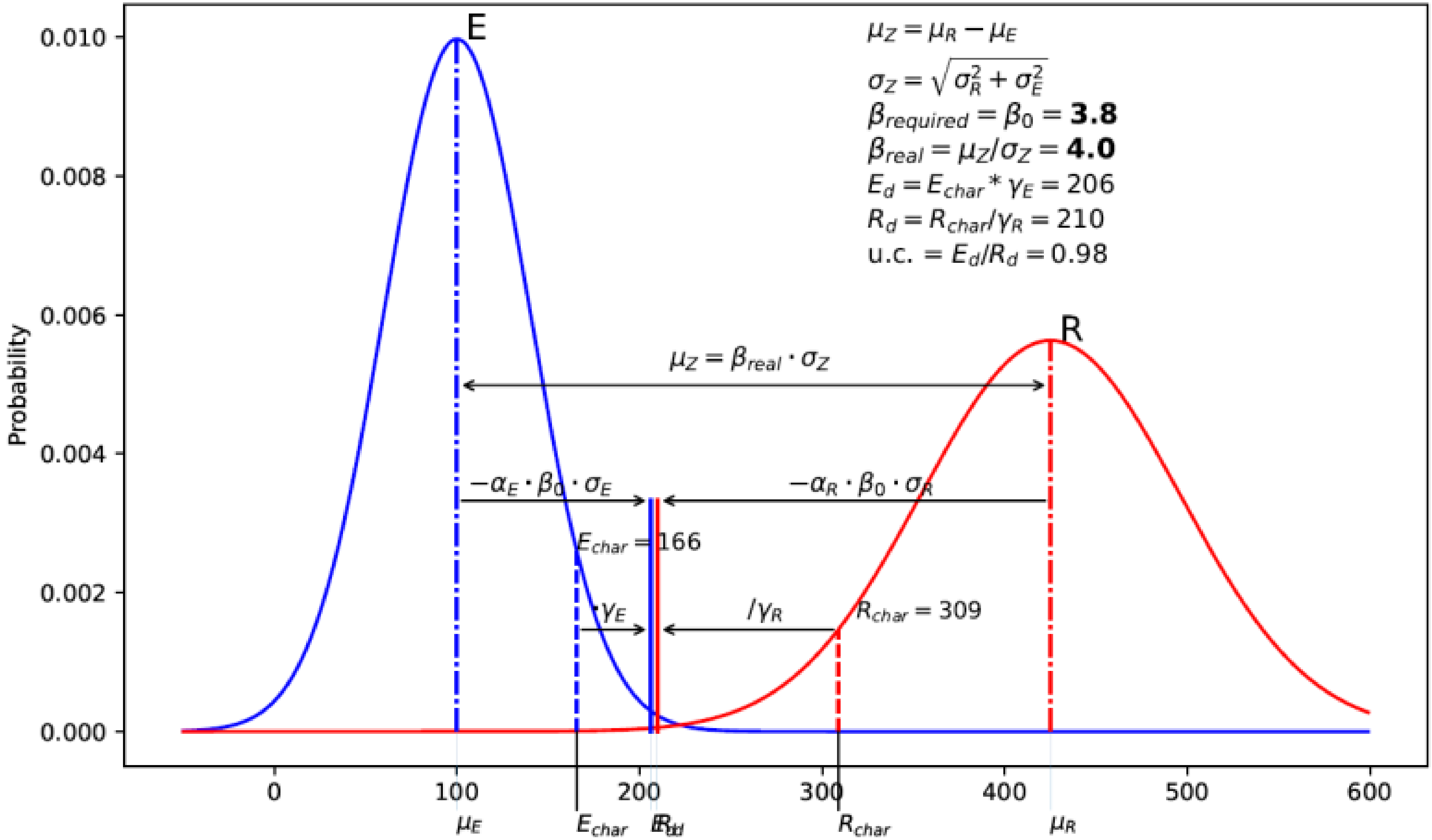
$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 450$
$\sigma_R = 75.00$
$v_R = 0.17$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



$\mu_E = 100$
$\sigma_E = 40.00$
$v_E = 0.40$
$\gamma_E = (\mu_E - \alpha_E \cdot \beta_0 \cdot \sigma_E)/E_{char} = \mathbf{1.25}$

$\mu_R = 425$
$\sigma_R = 70.83$
$v_R = 0.17$
$\gamma_R = R_{char}/(\mu_R - \alpha_R \cdot \beta_0 \cdot \sigma_R) = \mathbf{1.47}$



Partial factors for LOADS are in three main categories:

G permanent loads (e.g. self weight, soil pressure, pretensioning) → γ_G

Q variable loads (e.g. wind, vehicles, people) → γ_Q

A accidental loads (e.g. blasts, impact, seismic) → γ_A

limit state	design situation or load combination	CC	γ_G un-favourable	γ_G favourable	γ_Q	γ_A
ultimate limit state (ULS)	persistent (permanent) or transient (temporary) design situation (fundamental combinations)	CC3	1.5	0.9	1.65	-
			1.3	0.9	1.65	-
		CC2	1.35	0.9	1.5	-
			1.2	0.9	1.5	-
		CC1	1.2	0.9	1.35	-
			1.1	0.9	1.35	-
	accidental design situations	all	1.0	1.0	1.3	1.0
	seismic design situations	all	1.0	1.0	1.0	1.0
serviceability limit state (SLS)	characteristic, frequent and semi-permanent design combinations	all	1.0	1.0	1.0	-

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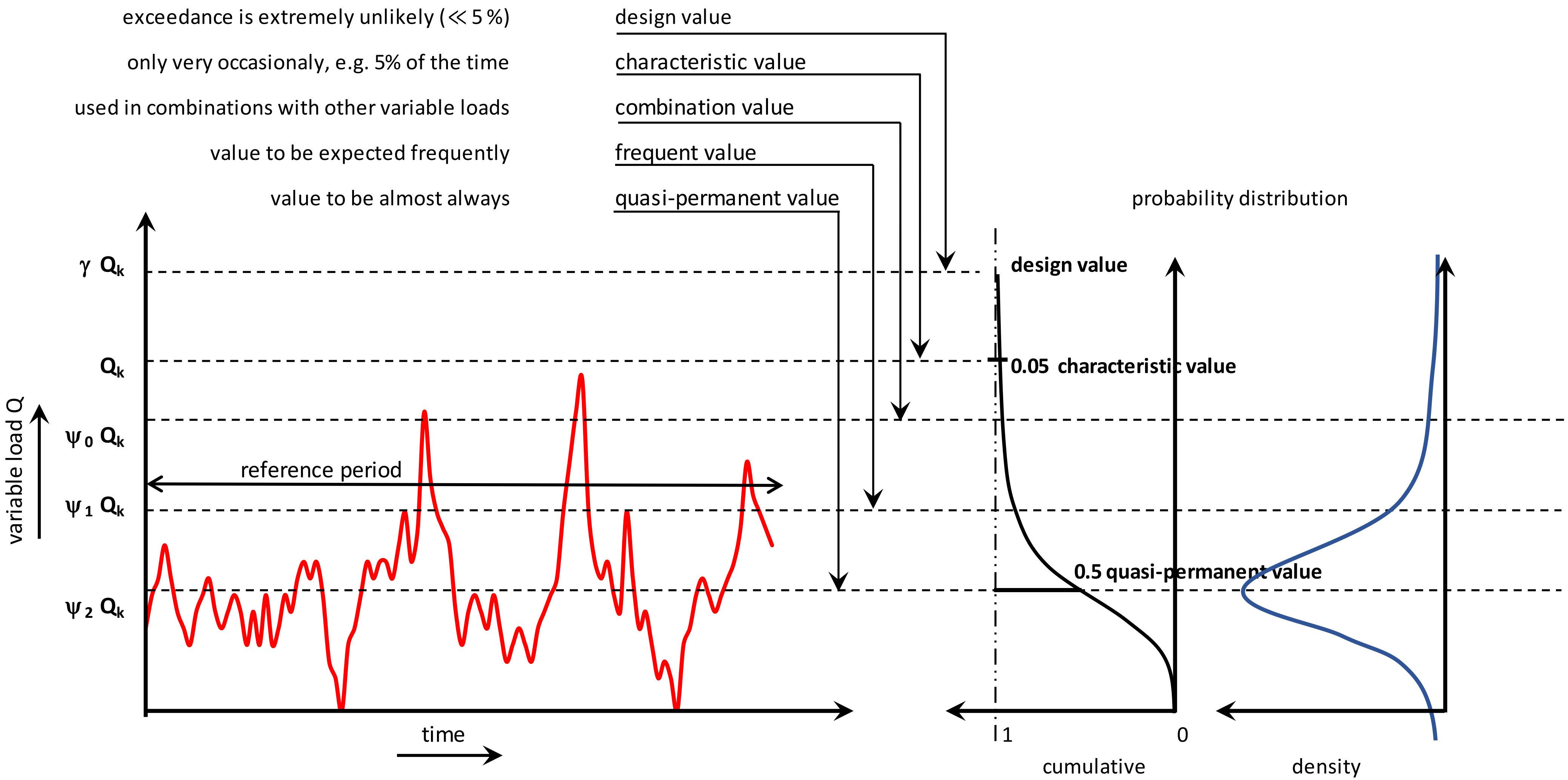

https://gitlab.tudelft.nl/roelschipper/ciem5000/-/blob/main/combination-factors_v2.xlsx

Table 2.12: Combination factors for road bridges

action	symbol		ψ_0	ψ_1	ψ_2
traffic loads (see prNEN-EN-1991-2 table 6.5 and 6.6)	gr1a (LM1 + footway and cycle-track loads)	TS	0.75	0.75	0
		UDL	0.40	0.40	0
		Footway+cycle-track loads	0.40	0.40	0
	gr1b (single axle)		0	0.75	0
	gr2 (horizontal forces)		0	0	0
	gr3 (pedestrian loads)		0	0.40	0
	gr4 (LM4 - crowd loading)		0	-	0
	gr5 (LM3 - special vehicles)		0	-	0
wind forces	$F_{W,k}$ persistent		0.6	0.2	0
	$F_{W,k}$ execution		0.8	-	0
	F_W		1.0	-	-
thermal actions	T_m		0.6	0.6	0.5
snow loads	$Q_{sn,k}$		0	0	0
water actions			i	i	i
construction actions	Q_c		1.0	-	1.0

Table 2.11: Combination factors for buildings (values in parentheses are from Dutch National Annex)

action	ψ_0	ψ_1	ψ_2
imposed loads in buildings:			
Category A: domestic, residential areas	0.7 (0.5)	0.5	0.3
Category B: office areas	0.7 (0.5)	0.5	0.3
Category C: congregation areas	0.7 (0.25)	0.7	0.6
Category D: shopping areas	0.7 (0.4)	0.7	0.6
Category E: storage areas	1.0	0.9	0.8
Category F: traffic area, vehicle weight $\leq 30\,\mathrm{kN}$	0.7	0.7	0.6
Category G: traffic area, $30\,\mathrm{kN}$vehicle weight $\leq 160\,\mathrm{kN}$	0.7	0.5	0.3
Category H: roofs accessible for normal maintenance and repair only	0.7 (0)	0.2 (0)	0
Construction loads: see NEN-EN-1991-1-6 (2005)	0.6 to 1.0	–	0.2
Snow loads on buildings			
- Finland, Iceland, Norway, Sweden	0.7	0.5	0.2
- Remainder of CEN member states, for sites located at altitude H $>$ 1000 m	0.7	0.5	0.2
- Remainder of CEN member states, for sites located at altitude H $\leq$ 1000 m	0.5 (0)	0.2	0
Wind loads in buildings: see NEN-EN-1991-1-4 (2005)	0.6 (0)	0.2	0
Temperature (non-fire) in buildings: see NEN-EN-1991-1-5 (2005)	0.6 (0)	0.5	0
Icing: see EN 1991-1-9	0.5	0.2	0
Standing water	–	–	–
Waves and currents: see EN 1991-1-8	–	–	–

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Design service life

Table 2.9: Design service life for buildings (draft prNEN-EN-1990 2021)

category of buildings	design service life T_{life} [years]
monumental building structures	100
building structures not covered by any other category	50
agricultural, industrial, and similar structures	25
temporary structures[a,b]	≤ 10

Table 2.10: Design service life for bridges (draft prNEN-EN-1990 2021)

category of bridges	design service life T_{life} [years]
bridges (including their foundations and tension components), other civil engineering structures supporting road or railway traffic[a]	100[b]
bridges where the main structural members have reduced protection[a]	50[b]
replacable structural parts other than tension components	25
temporary structures[c]	≤ 10

Design service life – load correction

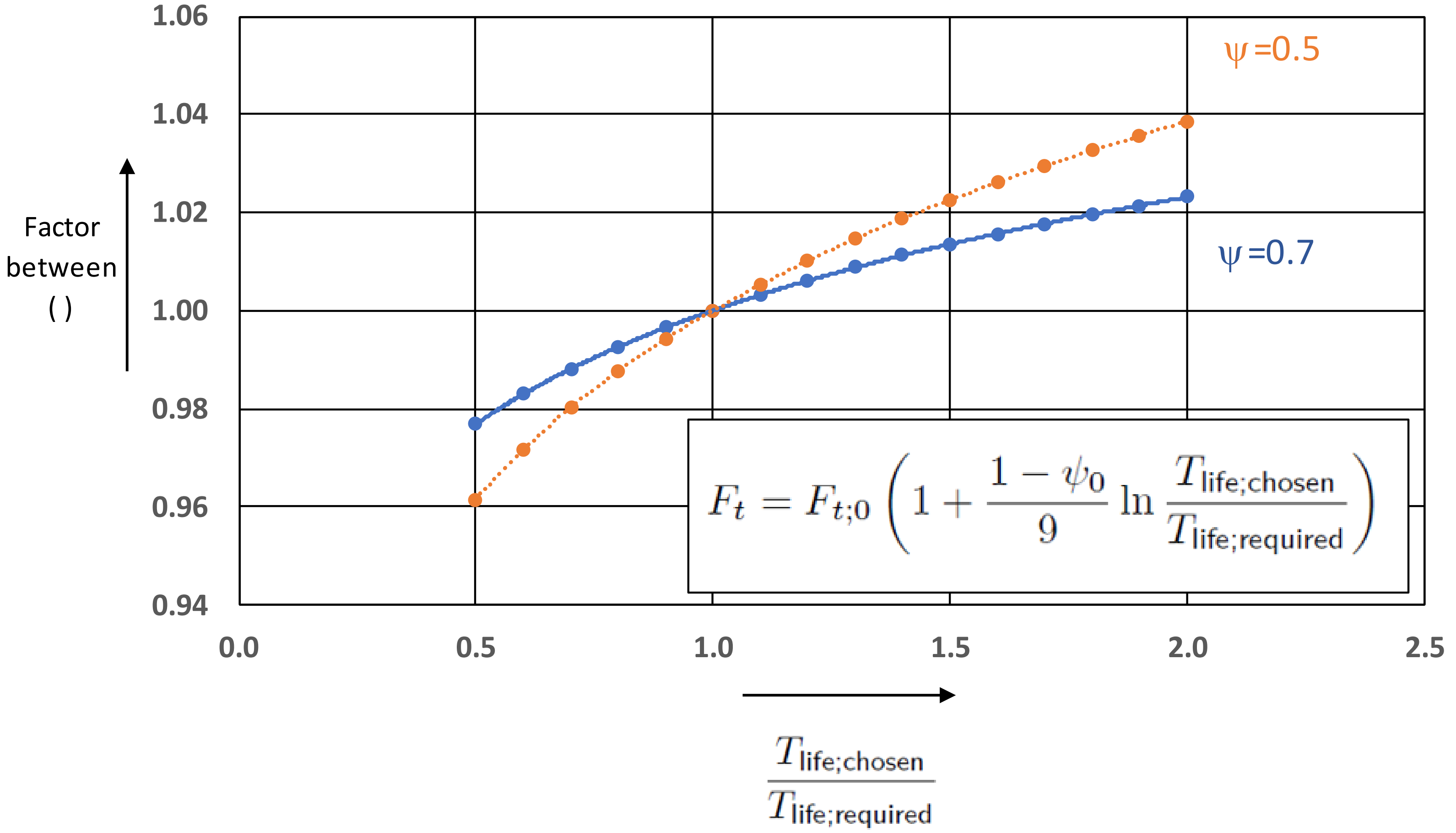
$$F_t = F_{t;0}\left(1 + \frac{1-\psi_0}{9}\ln\frac{T_{\text{life;chosen}}}{T_{\text{life;required}}}\right) \quad (2.9)$$

In which:

F_T	the adjusted characteristic value of the variable load to be used for the adjusted design service life
$F_{T;0}$	the characteristic value of the variable load for a design service life $T_{\text{life}} = 50$ years
ψ_0	combination factor, see below
$T_{\text{life;chosen}}$	adjusted design service life (may be either shorter or longer than $T_{\text{life;required}}$)
$T_{\text{life;required}}$	design service life $T_{\text{life;required}} = 50$ years

Design service life – load correction

Adjustment of characteristic value of variable loads for adjusted design service life



In which:

F_T	the adjusted characteristic value of the variable load to be used for the adjusted design service life
$F_{T;0}$	the characteristic value of the variable load for a design service life $T_{\text{life}} = 50$ years
ψ_0	combination factor, see below
$T_{\text{life;chosen}}$	adjusted design service life (may be either shorter or longer than $T_{\text{life;required}}$)
$T_{\text{life;required}}$	design service life $T_{\text{life;required}} = 50$ years

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Ultimate Limit State (ULS)

If **failure or collapse** is at risk, we call this limit state the Ultimate Limit State (or ULS).

An ULS often is an irreversible state that leads to **significant and permanent damage or even collapse**, concerning **safety of the structure itself** or the **people** using it.

Examples are loss of equilibrium, instability, material yield due to excess stress or fatigue.

Ultimate Limit State (ULS)

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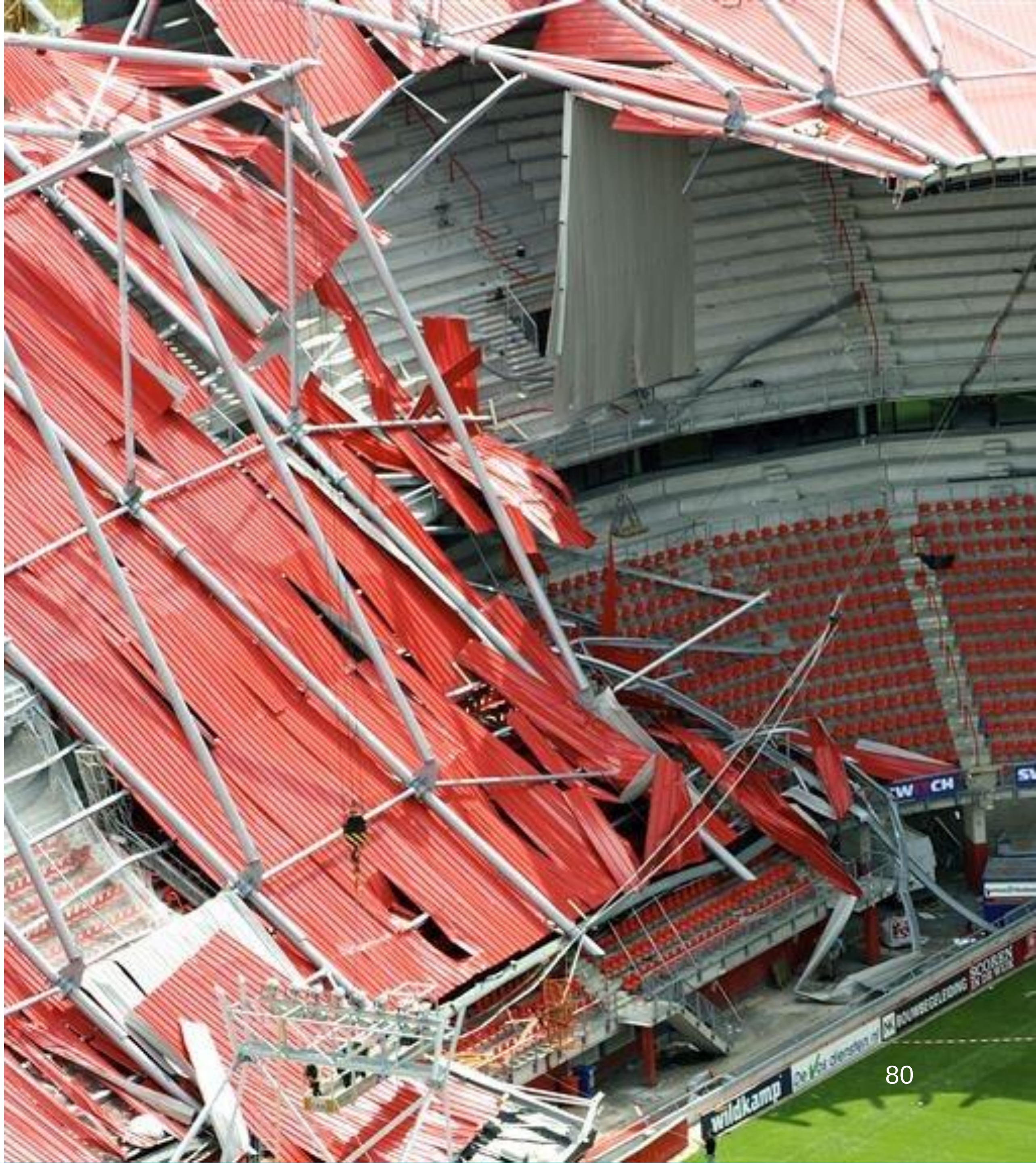
An ULS often is an irreversible state that leads to **significant and permanent damage or even collapse**, concerning **safety of the structure itself** or the **people** using it.

Examples are loss of equilibrium, instability, material yield due to excess stress or fatigue.



Example ULS: collapse stadium grand stand

[video NEC-stadium]

Serviceability Limit State (SLS)

The Serviceability Limit State (or SLS) is reached when **deformations, vibrations or deflections** are becoming so large that proper functioning (**service**) of the structure is no longer possible

or when **comfort of occupants** is at risk, although the structural reliability is not (yet) at stake.

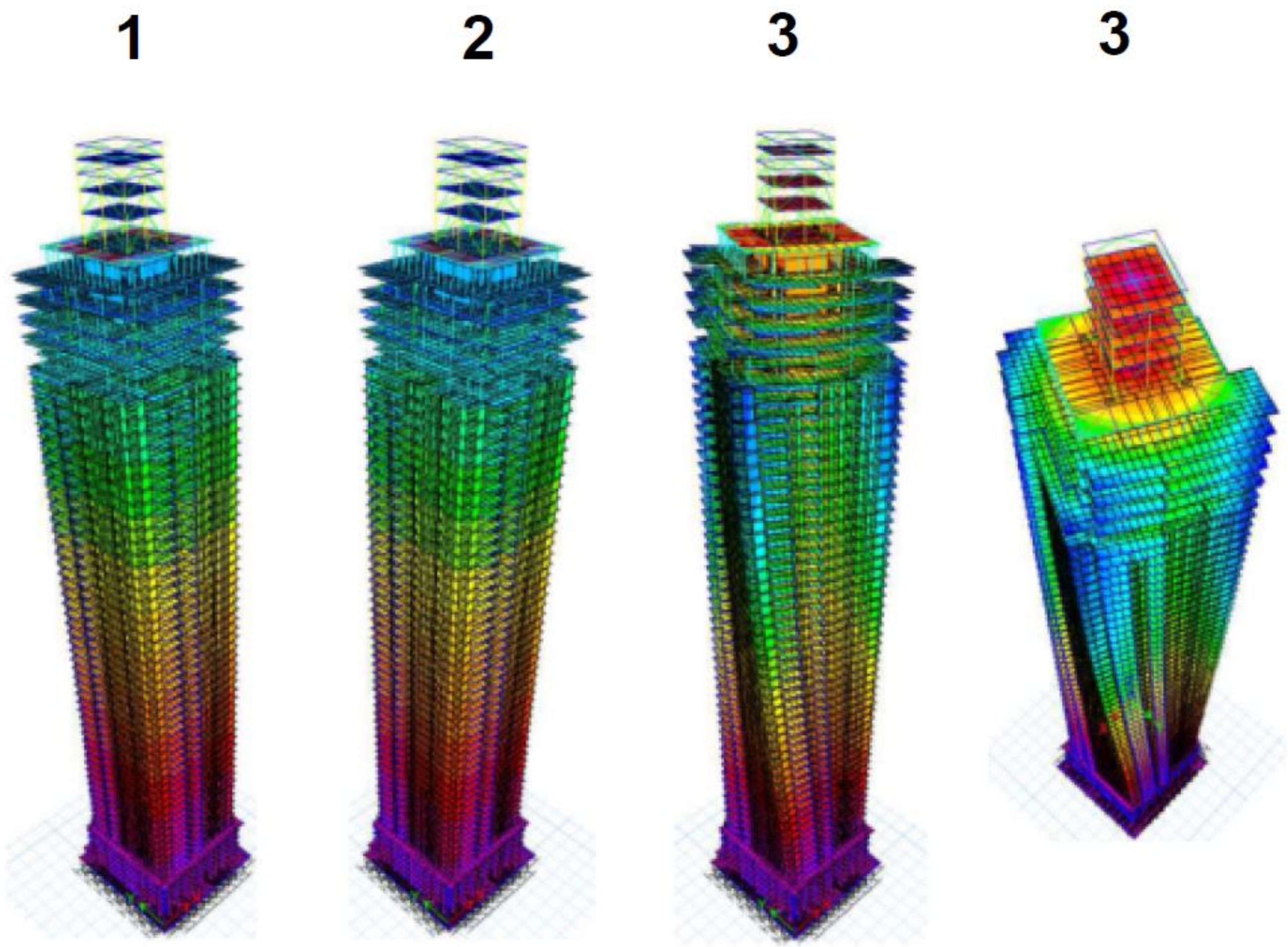
Beyond SLS, the structure is no longer able to perform its **service or the durability** of the structure might be at risk (e.g. crack width in concrete becomes too large, or corrosion occurs).

Also **architectural damage** (e.g. discolouring, cracks, problems with airtightness) is often considered as SLS.

An SLS may in many cases be a **reversible state**, that can be made undone after the load has reduced again.

However, it can also be considered as **irreversible damage** which is not of major and direct significance for the structure's structural reliability (you might think of small cracks in walls or permanent deformation as a result of creep). Repair or maintenance is considered an acceptable way of mitigating the effects of passing the SLS-threshold.

Example SLS check: Zalmhaventoren Rotterdam (guest lecture BAM) modal shape analysis - torsional acceleration and displacements



Eigenfrequenties in gescheurde toestand BGT									
Case	Mode	Period	Freq	UX	UY	Sum UX	Sum UY	RZ	Sum RZ
		sec	Hz						
Modal	1	4.10	0.24	0.53	0.04	0.53	0.04	0.00	0.00
Modal	2	4.05	0.25	0.04	0.53	0.57	0.57	0.00	0.00
Modal	3	1.94	0.51	0.00	0.00	0.57	0.57	0.00	0.56
Modal	4	0.77	1.30	0.00	0.21	0.57	0.78	0.00	0.00
Modal	5	0.76	1.32	0.20	0.00	0.77	0.78	0.00	0.00
Modal	6	0.59	1.71	0.00	0.00	0.77	0.78	0.00	0.20

Tabel 9. Eigenfrequenties in gescheurde toestand BGT.

Eigenfrequenties in gescheurde toestand UGT									
Case	Mode	Period	Freq	UX	UY	Sum UX	Sum UY	RZ	Sum RZ
		sec	Hz						
Modal	1	4.56	0.22	0.53	0.04	0.53	0.04	0.00	0.00
Modal	2	4.52	0.22	0.03	0.53	0.56	0.56	0.00	0.00
Modal	3	2.21	0.45	0.00	0.00	0.56	0.56	0.55	0.55
Modal	4	0.89	1.12	0.00	0.20	0.56	0.76	0.00	0.55
Modal	5	0.88	1.13	0.19	0.00	0.76	0.76	0.00	0.55
Modal	6	0.66	1.52	0.00	0.00	0.76	0.76	0.19	0.74

Tabel 10. Eigenfrequenties in gescheurde toestand UGT.

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Load combinations

ULS: $$\sum_{j\geq 1} \gamma_{G,j}\mathsf{G}_{k,j} + \gamma_P\mathsf{P} + \gamma_{Q,i=1}\mathsf{Q}_{k,i=1} + \sum_{i>1} \gamma_{Q,i}\psi_{0,i}\mathsf{Q}_{k,i} \quad (2.10)$$

G_k, P, Q_k	characteristic values for permanent, prestress and variable loads (for prestress $P_k = P$)
γ_G, γ_P, γ_Q	partial load factors for permanent, prestress and variable loads (γ_G and γ_Q from Table 2.7 on page 19, γ_P from material codes)
j	index counting permanent loads (1 or more)
$i = 1$	index counting the first variable load as dominant
$i > 1$	index counting remaining variable loads as non-dominant
$\psi_{o,i}$	combination value for all remaining variable loads with index count $i > 1$
$+$	to be read as: "to be combined with". Could be either a positive or negative value, depending on which of the two results in the worst load for the structure.

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Load combinations

ULS:

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} + \gamma_P P + \gamma_{Q,i=1} Q_{k,i=1} + \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \quad (2.10)$$

choose one variable load as the dominant variable load (numbered i=1)

choose all other variable loads (numbered i = 2, …, n) as non-dominant by using **combination factor ψ_0**

repeat this procedure by alternating all variable loads as governing ones until you find the load combination that results in the worst effect on the structure

this will generally result in **MANY** combinations!

and it can be **tricky** to find out **if** a combination is governing.

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RECAP

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