# Biasing techniques in FLUKA

Concept introduction and basic applications

Introduction to biasing

- Statistical bias: tendency causing a result to differ from the underlying fact

- In the context of FLUKA
  - Deliberately altering simulation parameters to improve variance or CPU time
  - This bias is countered by changing weights of particles

variance σ^2 ← → CPU time

Gaussian sampling (high stats)

Gaussian sampling (low stats)
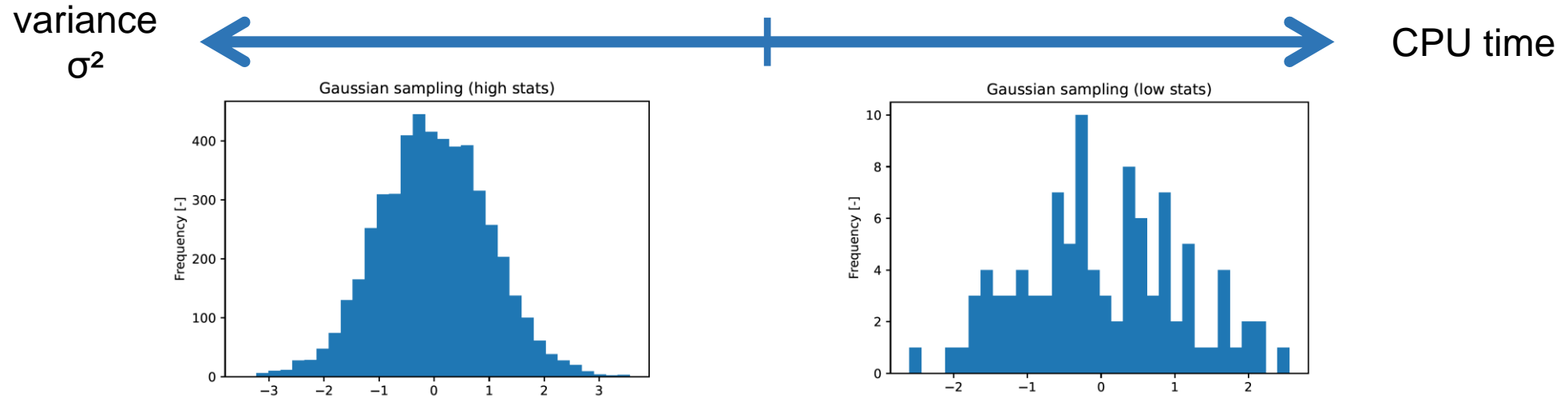
- Goodness of simulations : Figure of Merit $= \dfrac{1}{\sigma^2 t}$
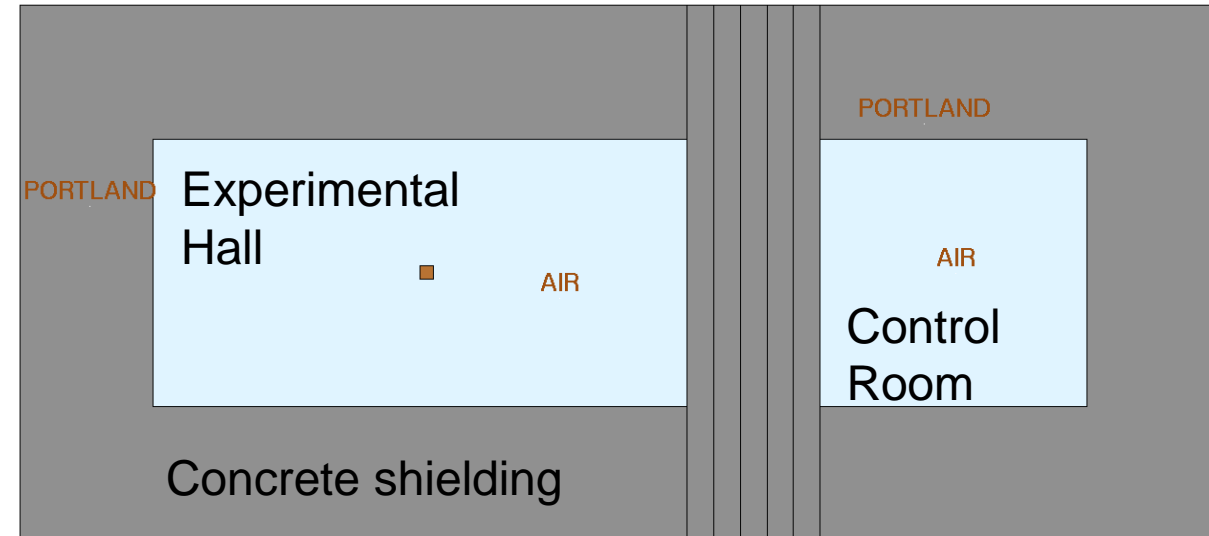 - The larger the better

Non-biased Monte Carlo simulations

Characteristics

- Samples from

  actual phase-space distributions

- Preserves correlations

- Reproduces fluctuations

Drawbacks

- Converges slowly

- Rare events are… "rare"
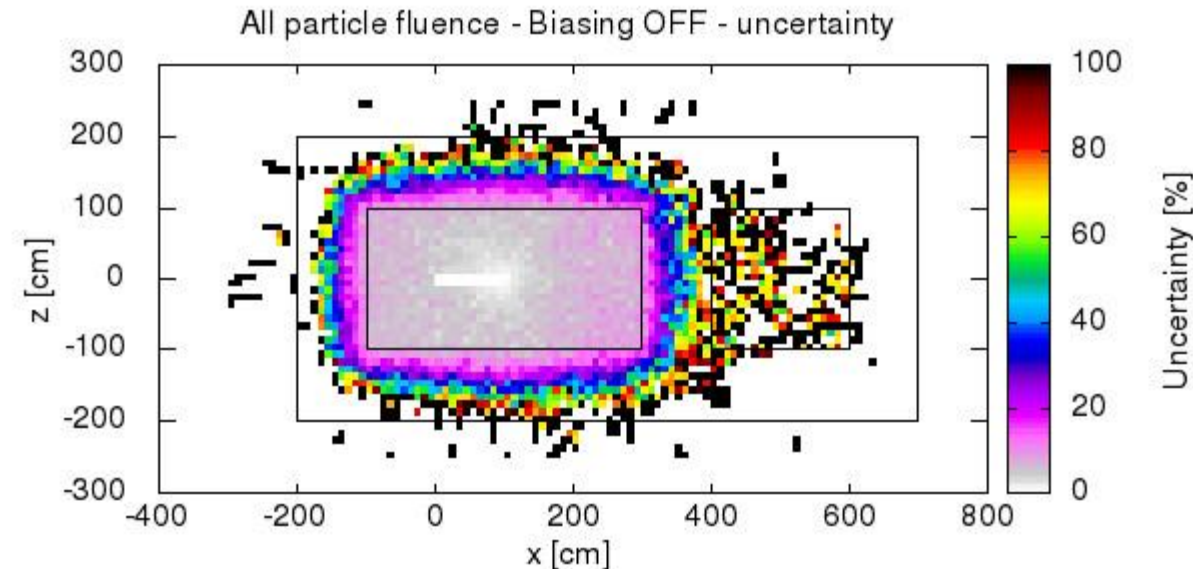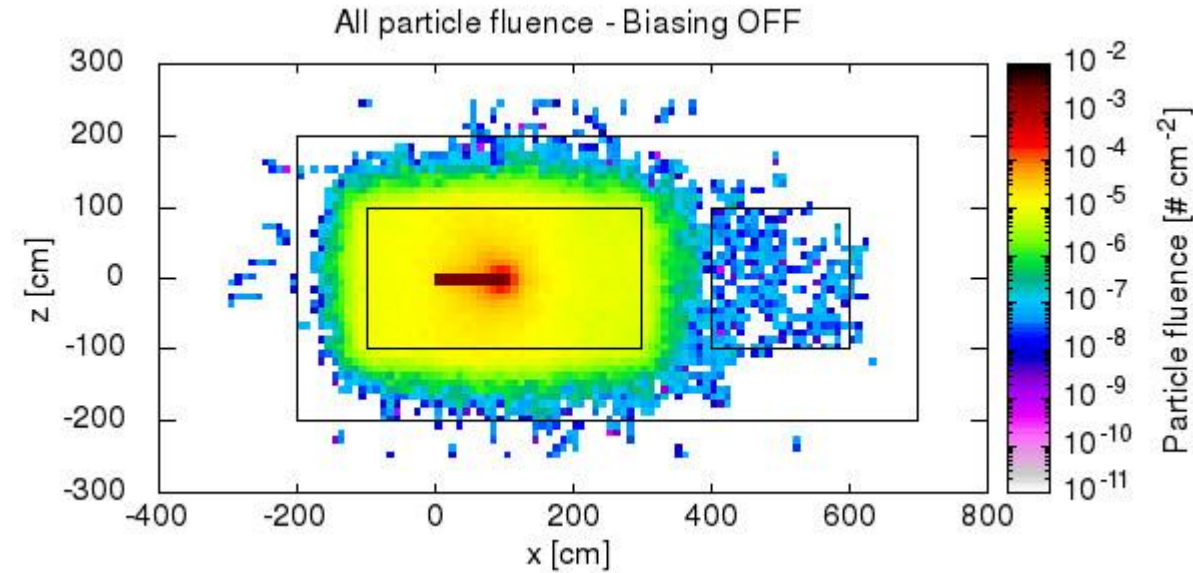
Non-biased Monte Carlo simulations

Characteristics

- Samples uniformly from

  the phase-space distribution

- Preserves correlations

- Reproduces fluctuations

Drawbacks

- Converges slowly

- Rare events are… "rare"

All particle fluence - Biasing OFF

All particle fluence - Biasing OFF - uncertainty

Biased Monte Carlo simulations

Characteristics

- Samples from distorted distributions

- Converges "quickly"

Drawbacks

- Cannot reproduce fluctuations and correlations

- Requires active reasoning and experience

- Requires user's time to be implemented

All particle fluence - Biasing ON

All particle fluence - Biasing ON - uncertainty
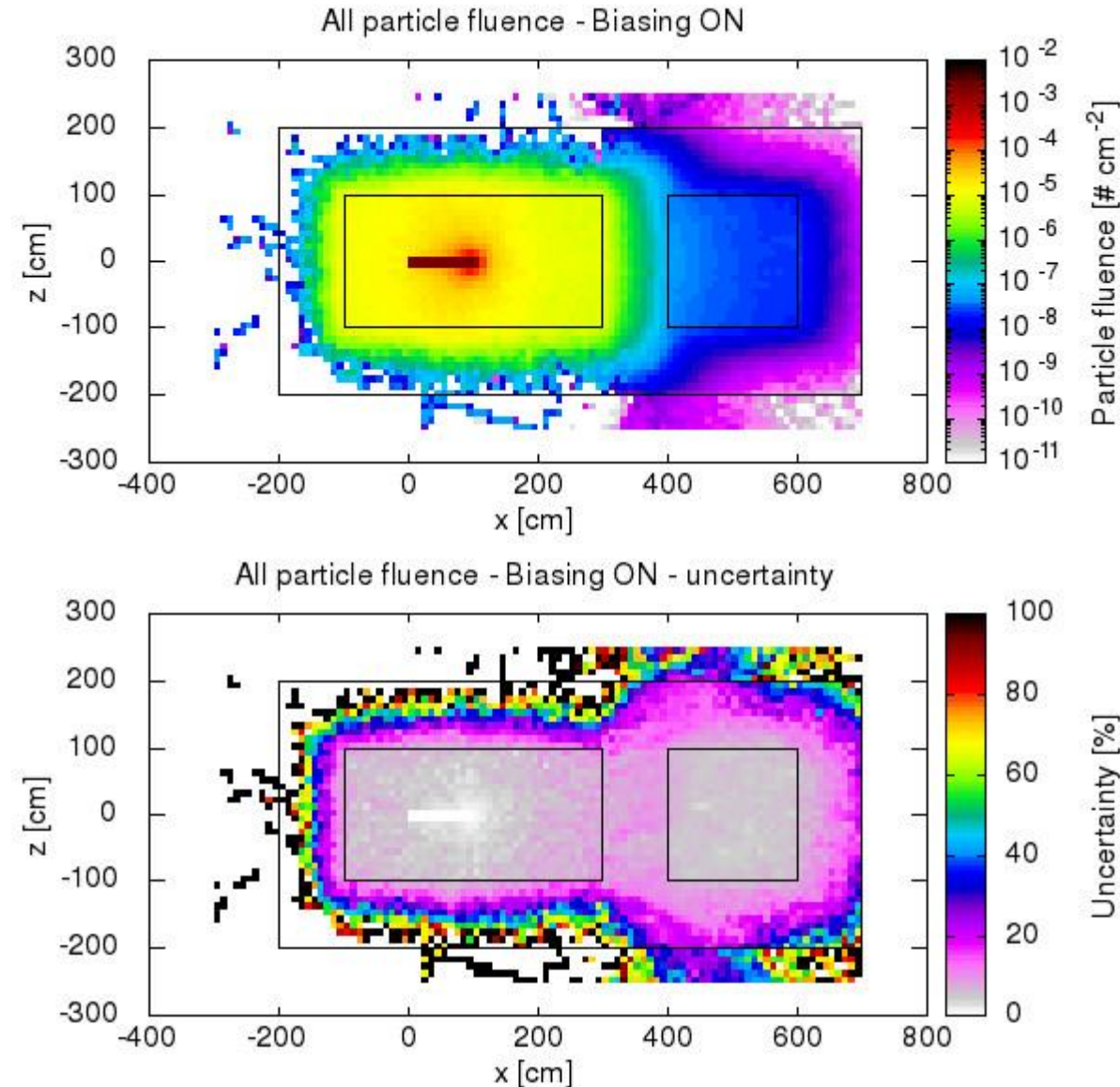
Biasing techniques in FLUKA

- *Region Importance Biasing* (**BIASING**)
- *Mean Free Path Biasing* (**LAM-BIAS**)

During this lessons we will only look at these 2 types

- Leading Particle Biasing (**EMF-BIAS**)
- Multiplicity Tuning (**BIASING**)
- Lifetime / Decay-length Biasing (**LAM-BIAS**)
- Weight Windows (**WW-FACTO**, **WW-THRES**, **WW-PROFI**)
- Low-energy neutrons non-analogue absorption (**LOW-BIAS**)
- Low-energy neutrons downscattering (**LOW-DOWN**)
- User defined biasing (usbset.f , usimbs.f)

Region Importance Biasing

Input card: **BIASING**

Region Importance Biasing

- Input card: **BIASING**

- Simplest form of biasing

- Applied when a particle crosses a region boundary (e.g. from Region1 to Region2)

- Based on *relative importance* of the two adjacent regions:

$$R = i_2/i_1 = \text{"importance of Region2" / "importance of Region1"}$$

- Combination of two algorithms (see next slides):
  - For R>1: *Surface Splitting*
  - For R<1: *Russian Roulette*

- Allows to compensate for attenuation (due to distance or absorption)

- Can maintain a uniform population

- Can be tuned per particle type

- Multiple **BIASING** cards are allowed

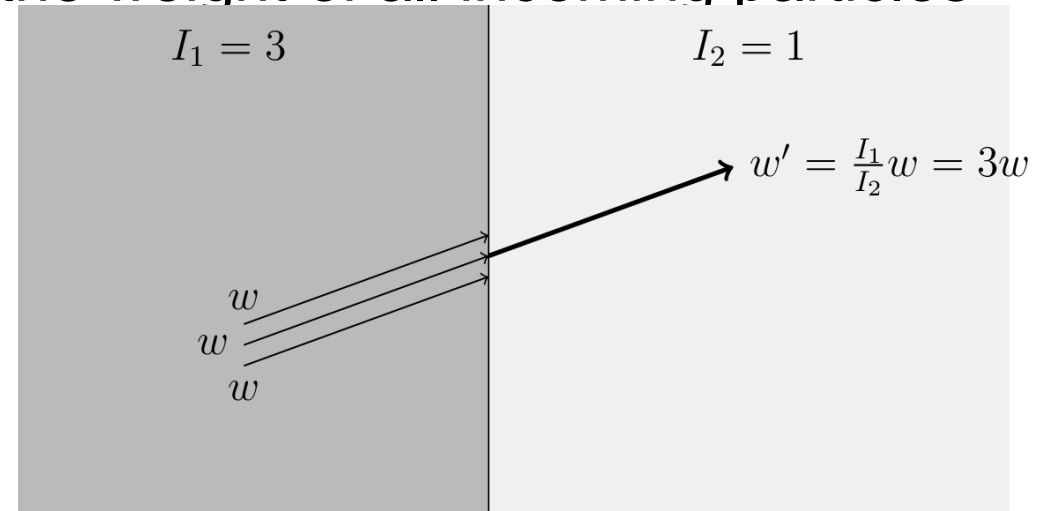# Region Importance Biasing

Surface Splitting

- Moving toward a higher importance region, *R>1*

- $n = R = i_2/i_1$ particle *replicas* are created

- *Weight* of replicas is $w = 1/R = i_1/i_2 < 1$

- Total weight of all replicas is equal to the weight of the original particles

- FLUKA allowed values: $5^{-1} \leq R \leq 5$

$I_1 = 1$ $I_2 = 3$

$w' = w/3$

$w' = w/3$

$w' = w/3$

w
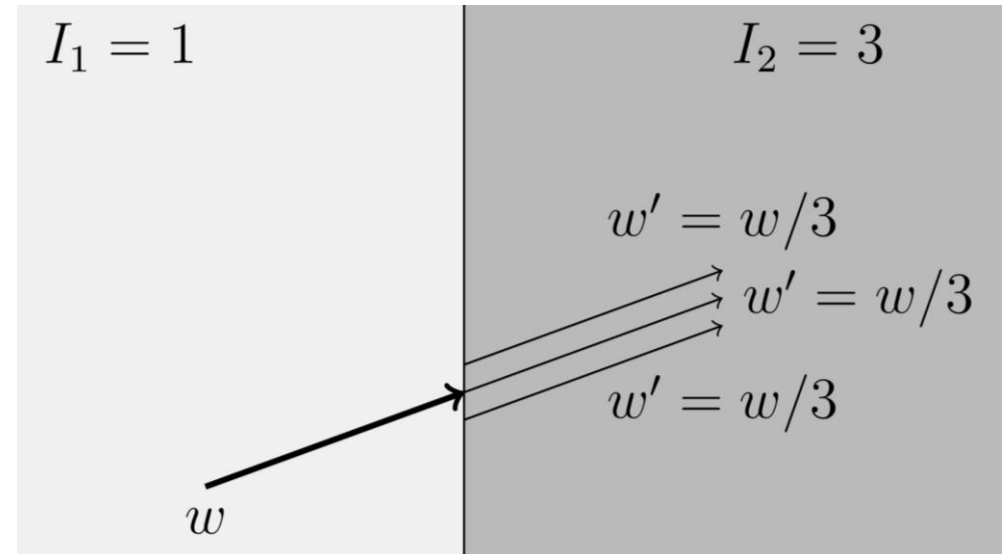
Region Importance Biasing

Russian Roulette

- Moving toward a lower importance region, $R<1$

- Particle have a survival probability $P_s = R = i_2/i_1$

- *Weight* of surviving particles increases: $w = 1/R = i_1/i_2 > 1$

- Weight of all surviving particles is equal to the weight of all incoming particles

- FLUKA allowed values: $5^{-1} \leq R \leq 5$
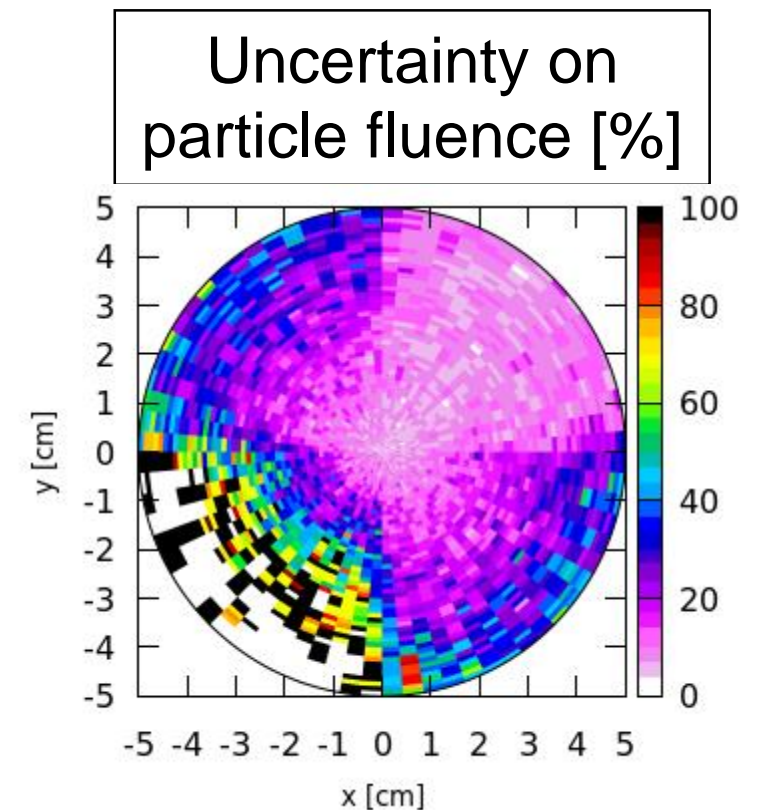

I : importance, w: particle weight
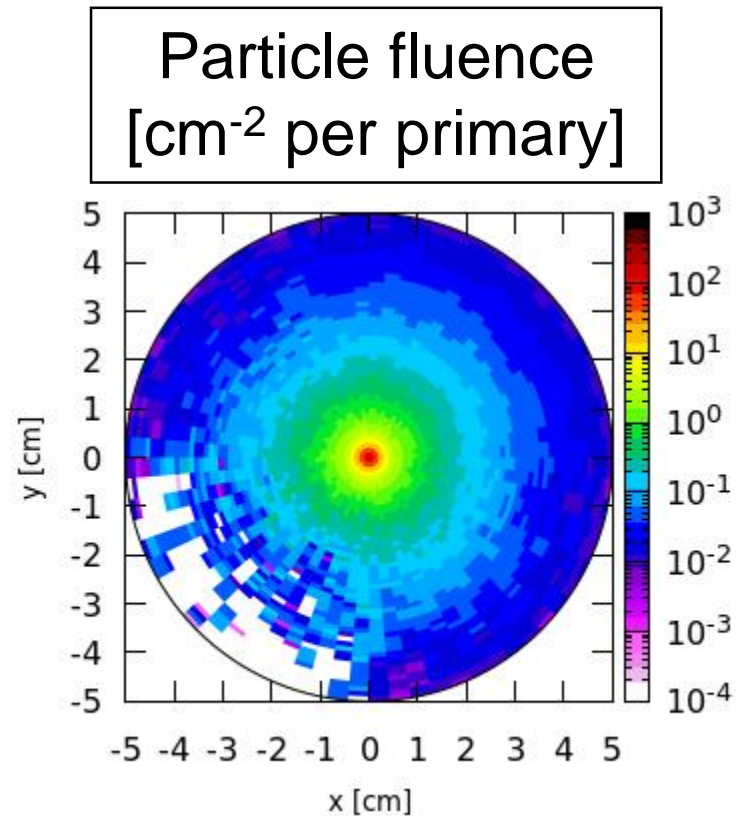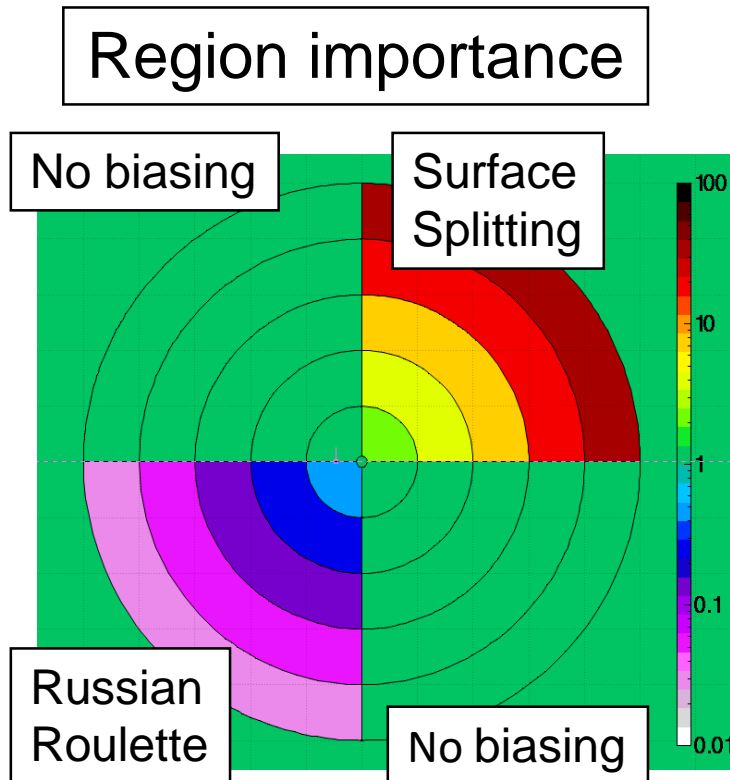Particle survives with probability $I_2/I_1 = 1/3$
Surviving particle weight increased by $I_1/I_2 = 3$

Region Importance Biasing

Example

- 200 MeV electrons on a cylindrical copper target (5 cm radius, 10 cm deep)
- 5000 primaries

Region importance

No biasing | Surface Splitting

Russian Roulette | No biasing

Particle fluence [cm^{-2} per primary]

Uncertainty on particle fluence [%]

Region Importance Biasing

Drawbacks

- Replicas histories differ because of dE/dx fluctuations and multiple scattering, therefore, when crossing into a low density region (e.g. vacuum, air) correlations between replicas can be relevant

- Could require geometry changes

    e.g: how to deal with a geometry like this?

R_Sour - where the source is	
R_Sh1 - shielding material 1	*R_strange* - made of a single material
R_Sh2 - shielding material 2	
R_Sh3 - shielding material 3	
R_Sh4 - shielding material 4	
R_of_int - location under investigation	

Region Importance Biasing

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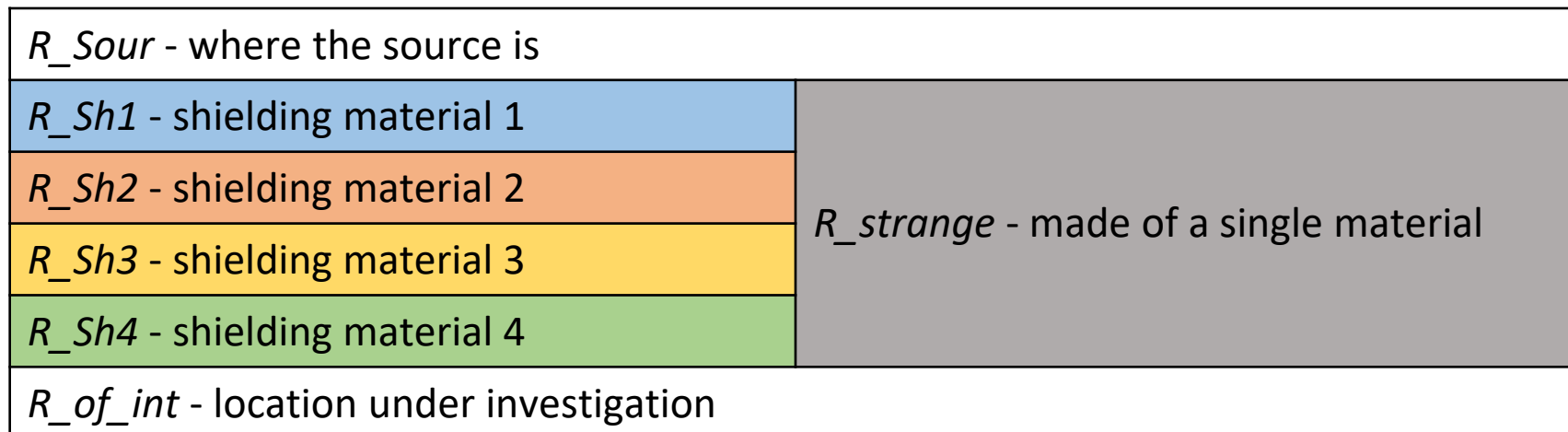
  e.g: how to deal with a geometry like this?

R_Sour - region_importance=1	
R_Sh1 - region_importance=2	*R_strange* - region_importance=?
R_Sh2 - region_importance=4	
R_Sh3 - region_importance=8	
R_Sh4 - region_importance=16	
R_of_int - region_importance=32	

Region Importance Biasing

Input card: **BIASING**

- *Type*
  - all particles
  - Hadrons & muons
  - e+, e-,γ
  - low energy neutrons
- *Reg - to Reg - Step*
  - Standard FLUKA region selection
- *Imp*
  - Importance of the selected region(s)

Example explanation:
An *importance=25* is assigned
to *all particles* within *region=a2*

BIASING		Type: All particles ▼	RR:	Imp: 25
Opt: ▼	Reg: a2 ▼		to Reg: a2 ▼	Step:

Region Importance Biasing

Input card: **BIASING**

- *Type*
  - "all regions"

- *Part - to Part - Step*
  - Standard FLUKA particle range selection

- *Mod. M*
  - Modifying factor M

    Applied to the splitting factor or

    to the Russian Roulette probability

    Practical use: inhibit RIB for a specific particle

Example explanation:
A *modifying factor = 0* is assigned to *all region importances* for protons. With all region importances set to 0, we ensure that there is no region importance biasing for protons anywhere

Mean Free Path Biasing

Input card: `LAM-BIAS`

Mean Free Path Biasing

- Input card: `LAM-BIAS`

- Allows to…

  - *…multiply the inelastic nuclear interaction length of hadrons by a factor λ*
  - *…multiply the nuclear interaction length of photons and muons by a factor λ*

- Useful for thin or low density target problems

- Useful to enhance photonuclear reactions (see `PHOTONUC` card)

- Weight is adjusted

- It can be applied to specific materials and/or specific particles

- Multiple `LAM-BIAS` cards are allowed

Mean Free Path Biasing

Input card: **LAM-BIAS**

- *Type*
  - \<empty\>   *Interaction length biasing*
  - DCDRBIAS   Decay direction biasing (advanced topics)
  - DCY-DIRE   Decay direction biasing (advanced topics)
  - DECALL   Particle generation selection for **LAM-BIAS** (advanced topics)
  - DECPRI   Particle generation selection for **LAM-BIAS** (advanced topics)
  - GDECAY   Lifetime / decay-length biasing (advanced topics)
  - INEALL   Particle generation selection for **LAM-BIAS** (advanced topics)
  - INEPRI   Particle generation selection for **LAM-BIAS** (advanced topics)
  - N1HSCBS   Under development

Mean Free Path Biasing

Input card: **LAM-BIAS**

- *Type*
  - <empty>

- *× mean life*
  - Doesn't apply

- *× λ inelastic*
  - Interaction length correction factor

- *Mat*
  - Material where the correction factor applies

- *Part - to Part - Step*
  - Standard FLUKA particle selection

Example explanation:
Proton interaction length in *beryllium* is multiplied by a factor *correction factor=0.02* (reduced by a factor 50)
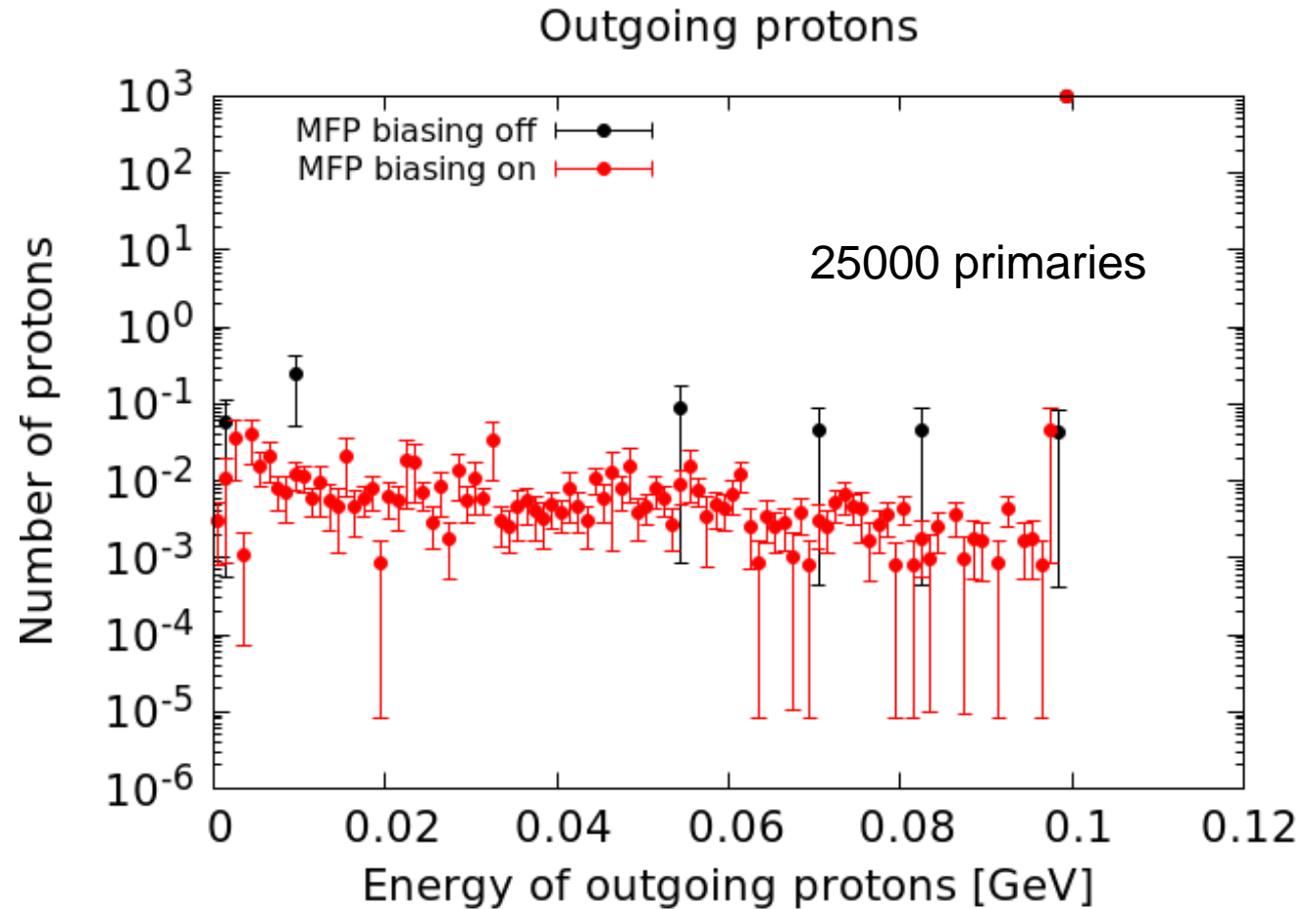
LAM-BIAS	Type: ▼	× mean life:	× λ inelastic: 0.02
Mat: BERYLLIU ▼	Part: PROTON ▼	to Part: ▼	Step:

Mean Free Path Biasing

Input card: `LAM-BIAS`

- Primaries: 100 MeV protons

- Target: 0.1 mm thick beryllium disk

- Spectrum of outgoing protons

- Black: no biasing applied

- Red: MFP biasing applied

LAM-BIAS	Type: ▼	× mean life:	× λ inelastic: **0.02**
Mat: **BERYLLIU** ▼	Part: **PROTON** ▼	to Part: ▼	Step:

Summary of the input cards seen

Summary of the input cards seen

- **BIASING**
  - Region Importance biasing (Surface Splitting and Russian Roulette)

- **LAM-BIAS**
  - Mean free path biasing (interaction length)
  - Lifetime / Decay-length biasing (not shown in these slides)