Biasing techniques in FLUKA

Concept introduction and basic applications

What is biasing?

- It is the use of "*Variance Reduction Technique*(s)" that…

  distort distributions and apply weights to particles to correct for the bias
- VRTs aim at reducing variance σ^2 or CPU time t
- Usually, reducing one quantity increases the other
- Usually, more than one VRT is applied at the same time
- Goodness of simulations can be estimated with a Figure of Merit: $FOM=1/(\sigma^2 \cdot t)$

  the larger the better: less time and smaller uncertainty

Non-biased Monte Carlo simulations

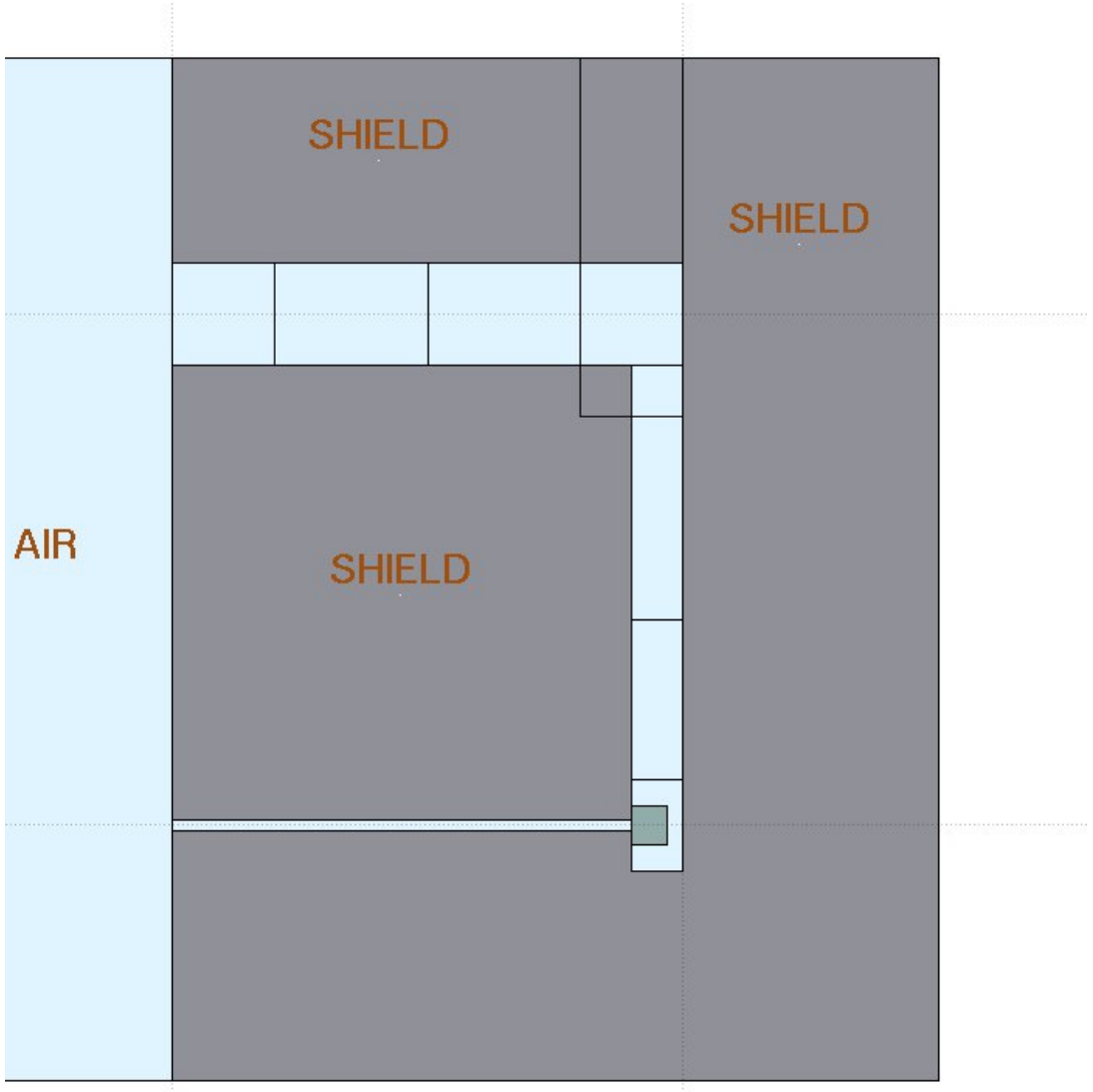
Characteristics

- Samples from

  actual phase-space distributions
- Preserves correlations
- Reproduces fluctuations

Drawbacks

- Converges slowly
- Rare events are… “rare”



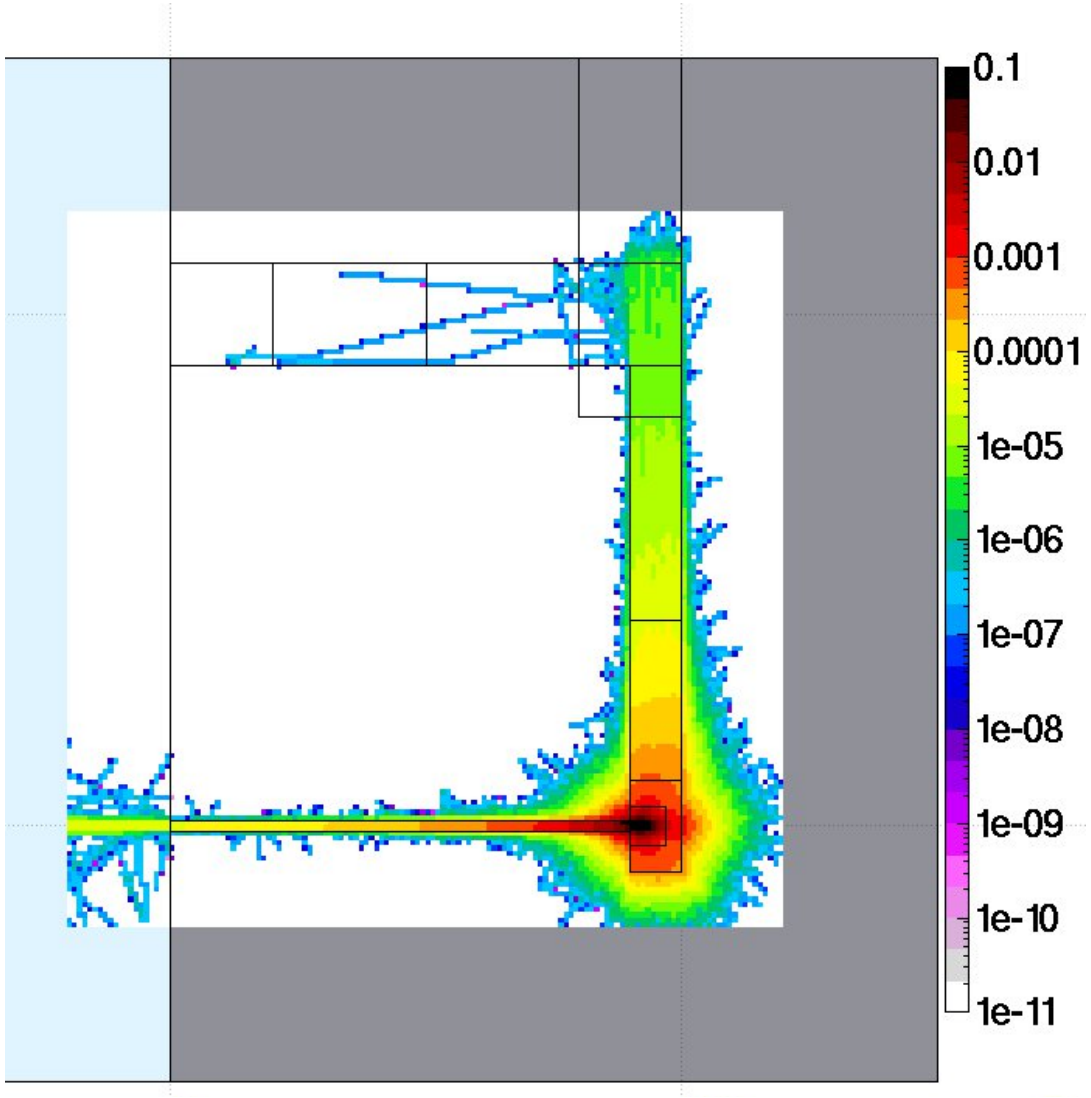
Non-biased Monte Carlo simulations

Characteristics

- Samples uniformly from the phase-space distribution
- Preserves correlations
- Reproduces fluctuations

Drawbacks

- Converges slowly
- Rare events are… “rare”



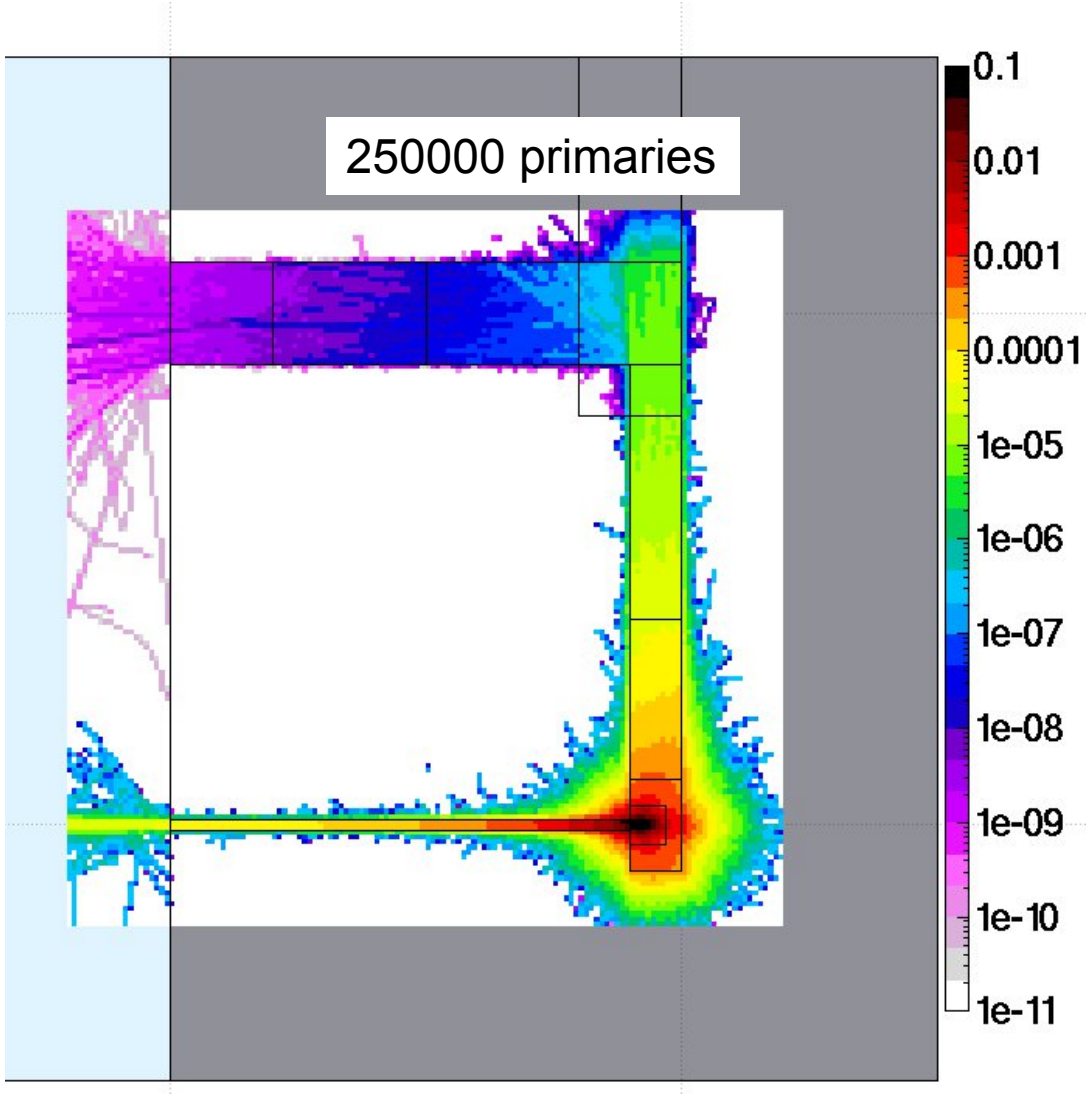
Biased Monte Carlo simulations

Characteristics

- Samples from distorted distributions
- Converges “quickly”

Drawbacks

- Cannot reproduce fluctuation and correlations
- Requires active reasoning and experience
- Requires user’s time to be implemented



Biasing techniques in FLUKA

- *Region Importance Biasing* (BIASING)
- *Leading Particle Biasing* (EMF-BIAS)
- *Multiplicity Tuning* (BIASING)
- *Mean Free Path Biasing* (LAM-BIAS)
- *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)

During this lessons we will only look at these 2 types

Region Importance Biasing

Input card: **BIASING**

Region Importance Biasing

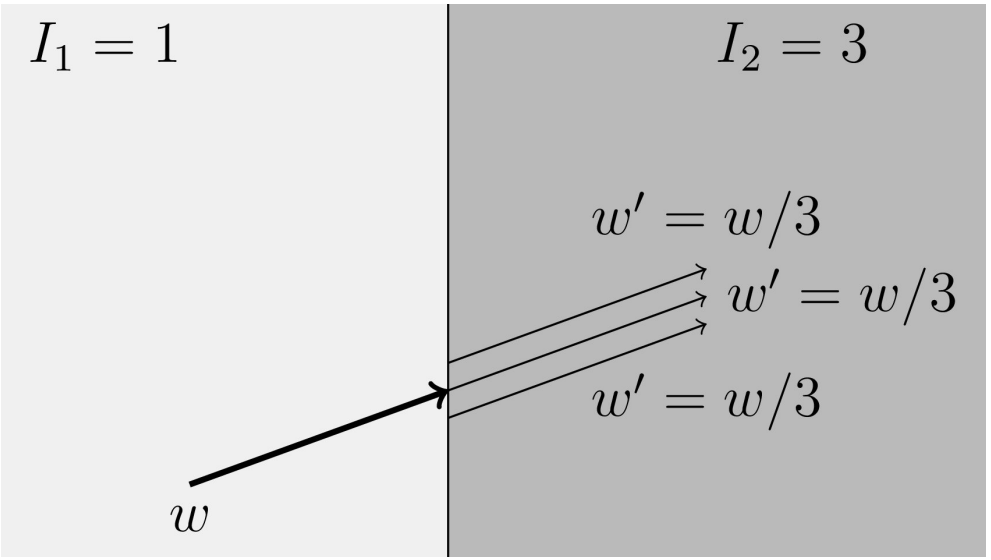
- Input card: **BIASING**
- Simplest form of biasing
- Applied when a particle crosses a region boundary (e.g. from Region1 to Region2)
- Based on *relative importance* of the two adjacent regions:

  $R = i_2/i_1$ = "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

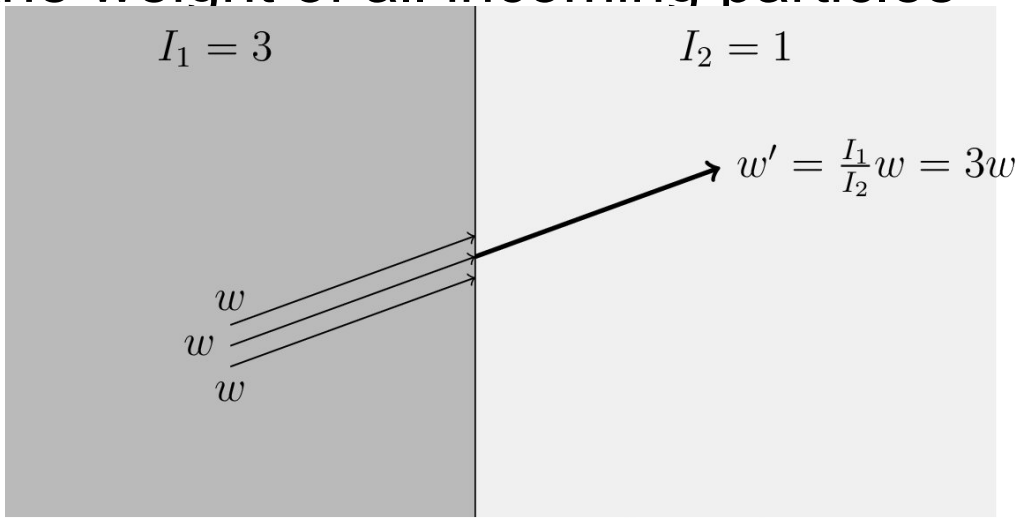
- Moving toward a higher importance region, $R>1$
- $n = R = i_2/i_1$ particle *replicas* are created
- *Weight* of replicas is $w = 1/R = i_1/i_2 < 1$
- Total weight of all replicas is equal to the weight of the original particles
- FLUKA allowed values: $5^{-1} \leq R \leq 5$



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: $5^{-1} \leq R \leq 5$



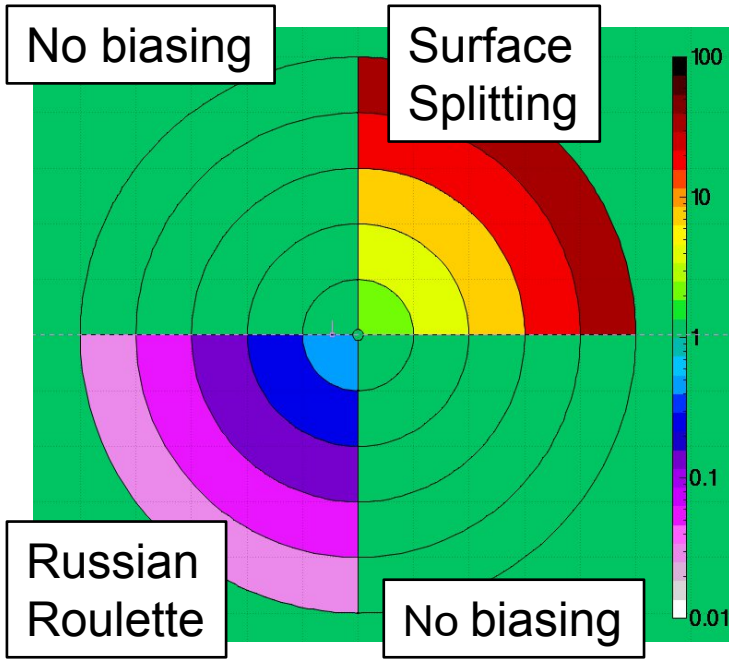
I : importance, w: particle weight
Particle survives with probability $I_2/I_1 = 1/3$
Surviving particle weight increased by $I_1/I_2 = 3$

Region Importance Biasing

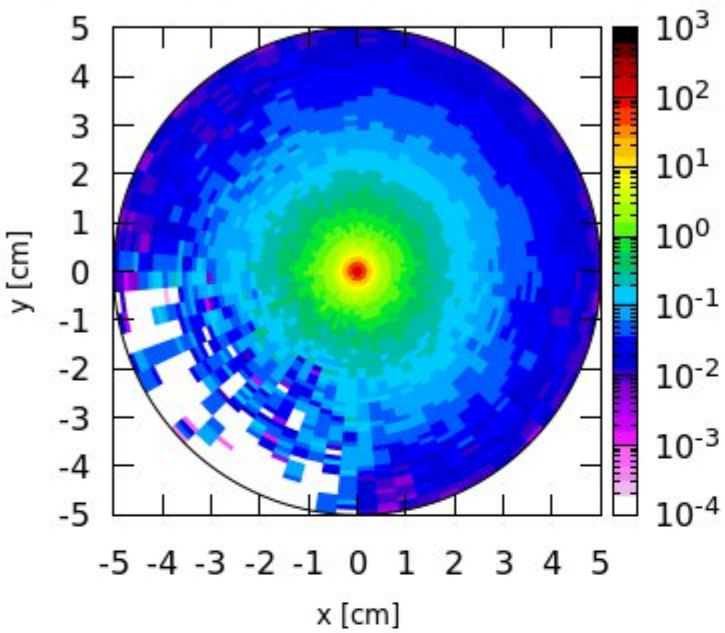
Example

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

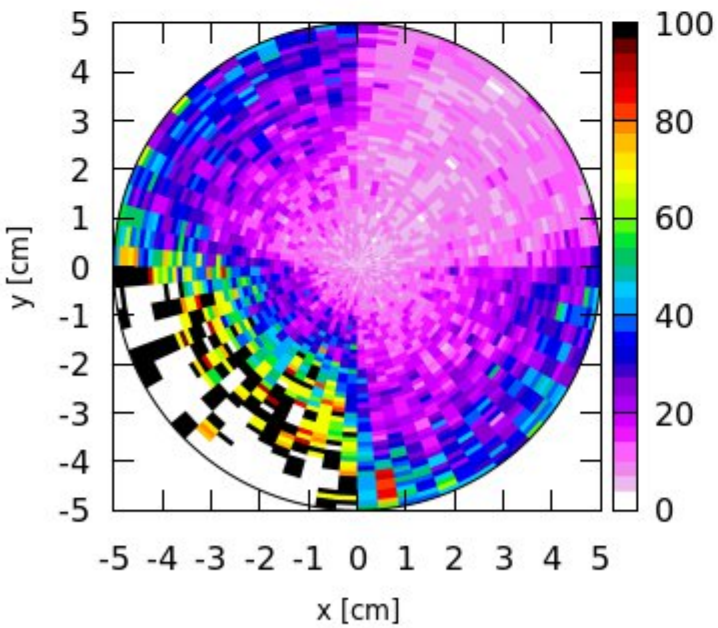
Region importance



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?

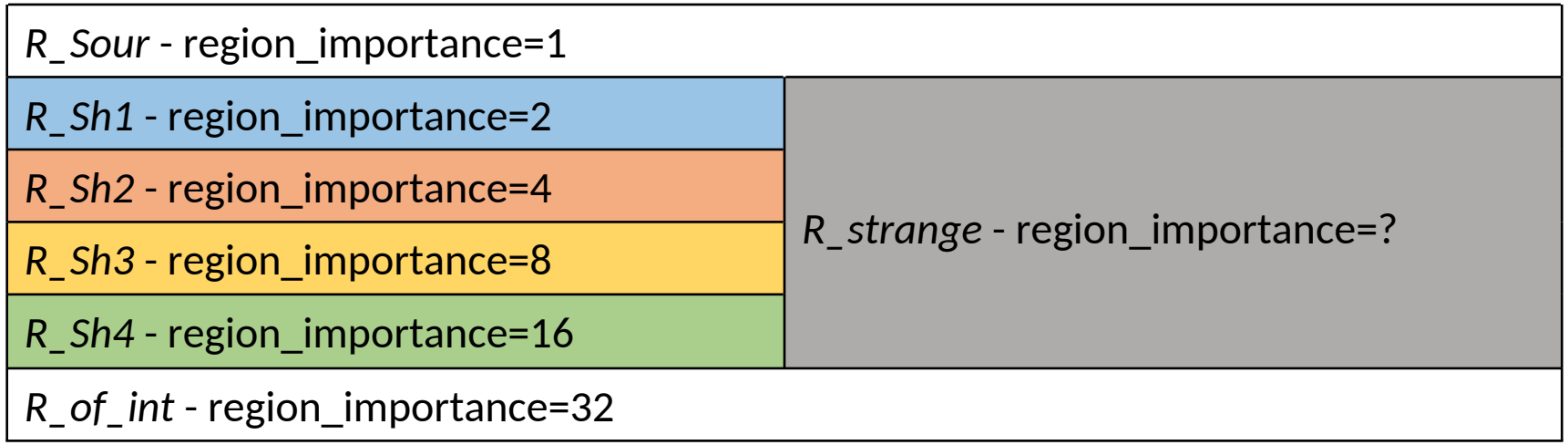
<table>
<tr><td colspan="2">*R_Sour* - where the source is</td></tr>
<tr><td>*R_Sh1* - shielding material 1</td><td rowspan="4">*R_strange* - made of a single material</td></tr>
<tr><td>*R_Sh2* - shielding material 2</td></tr>
<tr><td>*R_Sh3* - shielding material 3</td></tr>
<tr><td>*R_Sh4* - shielding material 4</td></tr>
<tr><td colspan="2">*R_of_int* - location under investigation</td></tr>
</table>

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?



Region Importance Biasing

Input card: **BIASING**

- *Type*
  - all particle
  - 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*

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 *protons* (id=1) in *all regions*
i.e. no region importance biasing for protons in any region

Leading Particle Biasing

Input card: **EMF-BIAS**

Leading Particle Biasing

- Input card: **EMF-BIAS**
- Applies only to electromagnetic interactions of electrons, positrons, and photons
- Interaction processes to be affected are selected one by one (see next slide)
- Two electromagnetic particles in the final state, only one is retained
- Applies only within selected regions
- Survival probability p proportional to energy
- Weight is adjusted $w' = w / p$
- Generally used to speed up simulations of electromagnetic showers
- Few surviving low-energy particles might generate strong fluctuations
- Multiple **EMF-BIAS** cards are allowed

Leading Particle Biasing

Input card: **EMF-BIAS**

- *Type*
  - LPBEMF *Leading Particle Biasing for ElectroMagnetic interaction in FLUKA*
  - LAMBEMF Lambda biasing (advanced topics)
  - LAMBCOMP Lambda biasing (advanced topics)
  - LAMBBREM Lambda biasing (advanced topics)
  - LBRREMF Lambda biasing (advanced topics)
  - LBRRCOMP Lambda biasing (advanced topics)
  - LBRRBREM Lambda biasing (advanced topics)

Leading Particle Biasing

Input card: **EMF-BIAS**

- *Type*
  - LPBEMF
  - …
- *Ethr e-e+ - Ethr γ*
  - Threshold below which LPB applies
    - For electrons: E = kinetic energy
    - For positrons: E = total energy plus rest mass energy
- *Processes to which LPB applies*
  - Self-explanatory
  - “Old bremss.” is a relic of the past for backward compatibility
- *Reg - to Reg - Step*
  - Standard FLUKA region selection

Leading Particle Biasing

Input card: **EMF-BIAS**

- *Type*
  - LPBEMF
- *Ethr e-e+ - Ethr γ*
  - Threshold below which LPB applies (*)
- *Processes to which LPB applies*
  - Self-explanatory
- *Reg - to Reg - Step*
  - Standard FLUKA region selection

Example explanation:
LPB is applied during *bremsstrahlung* and *pair production* processes, within *every other region (step=2)* between *region=a2* and *region=a8*, to *photons*, *electrons*, and *positrons* below a *20 MeV (*) energy threshold*

EMF-BIAS	Type: LPBEMF	Ethr e-e+: 0.02	Ethr γ: 0.02
Old bremss.: off	Bremsstrahlung: On	Pair Prod.: On	e+ ann @rest: off
Compton: off	Bhabha&Moller: off	Photo-electric: off	e+ ann @flight: off
	Reg: a2	to Reg: a8	Step: 2

*Beware of the different thresholds for electrons and positrons (see previous slide)

Summary of the input cards seen

Summary of the input cards seen

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

- **EMF-BIAS**
  - Leading Particle Biasing for electron, positron, and photon interactions

FLUKA