Biasing techniques in FLUKA

Concept introduction and basic applications

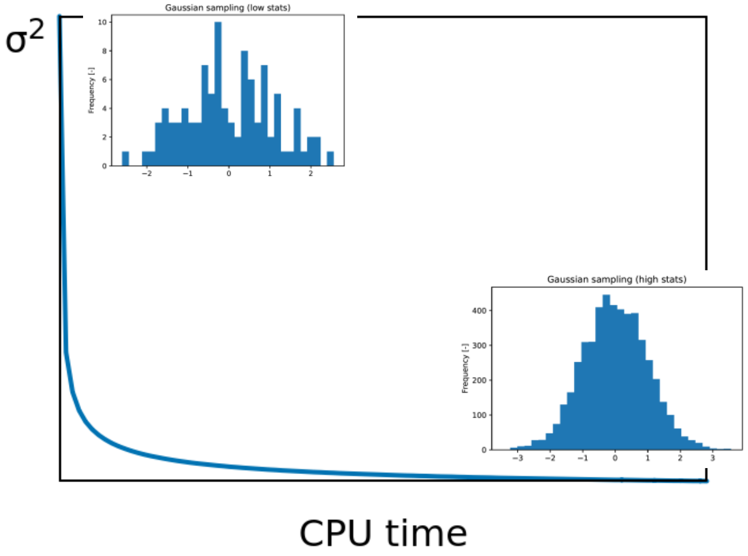
What is biasing?

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

  distort distributions and apply weights to particles to correct for the bias

- VRTs alter simulation parameters in order to

  reduce 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

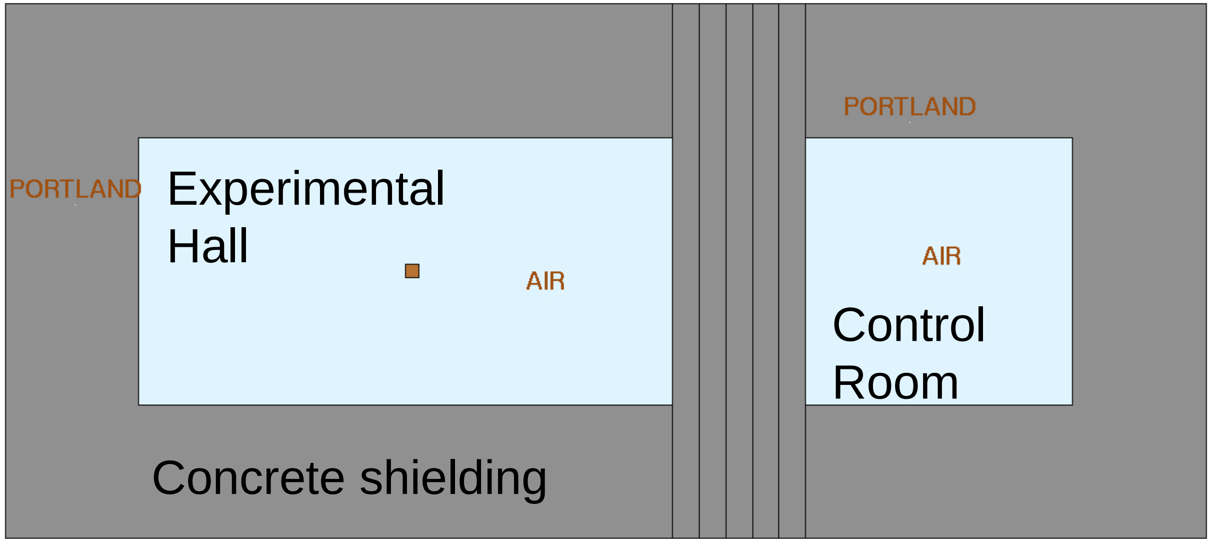
Characteristics

- Samples from

  actual phase-space distributions
- Preserves correlations
- Reproduces fluctuations

Drawbacks

- Converges slowly
- Rare events are… “rare”



Non-biased Monte Carlo simulations

200000 primaries

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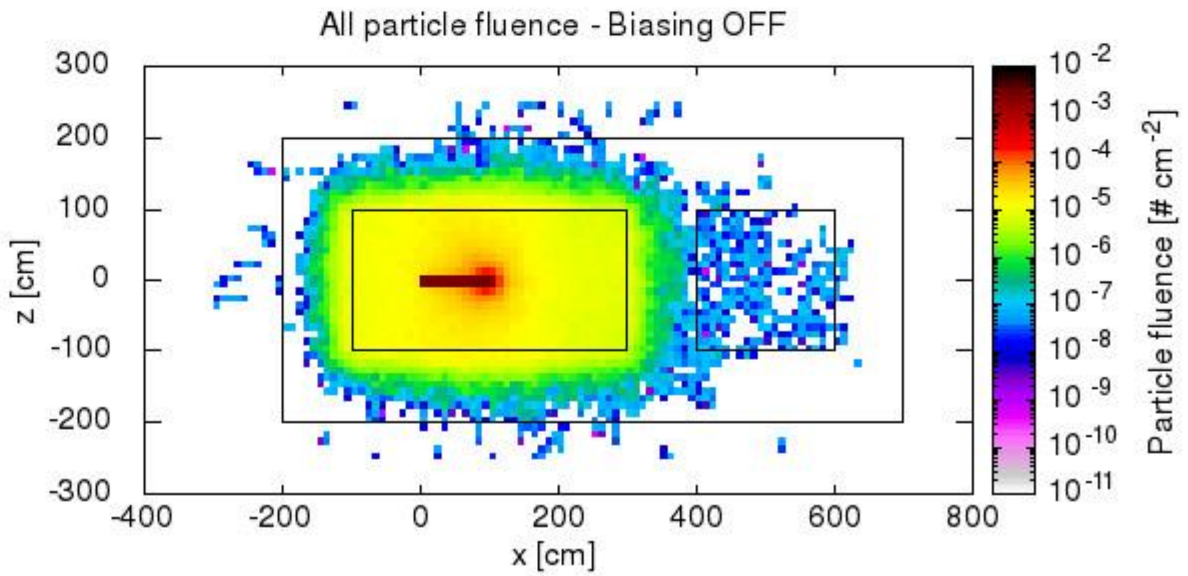
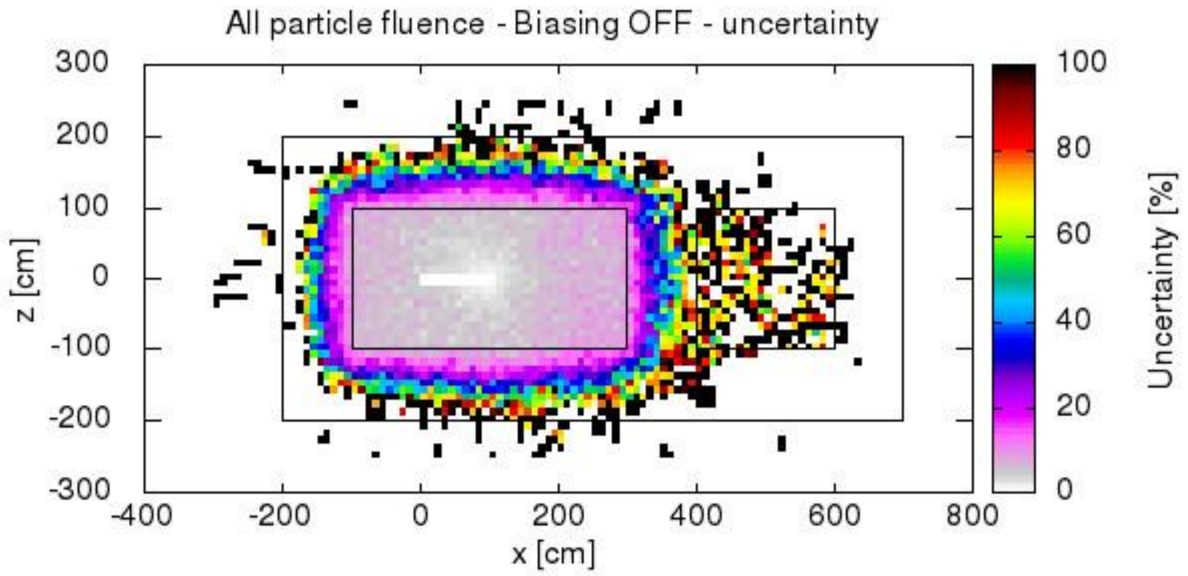




Biased Monte Carlo simulations

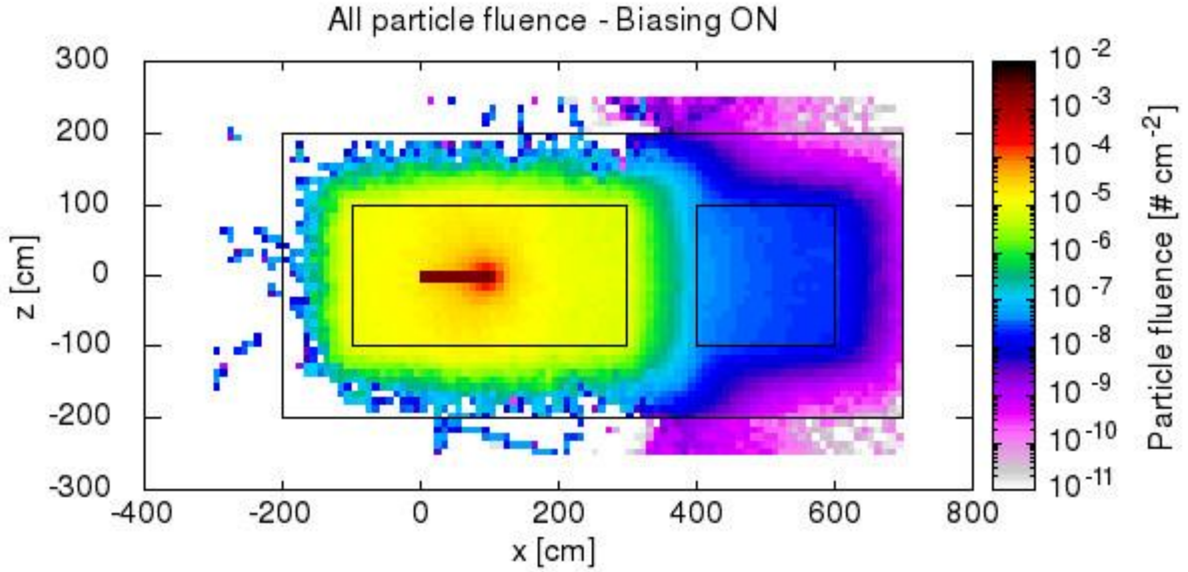
200000 primaries

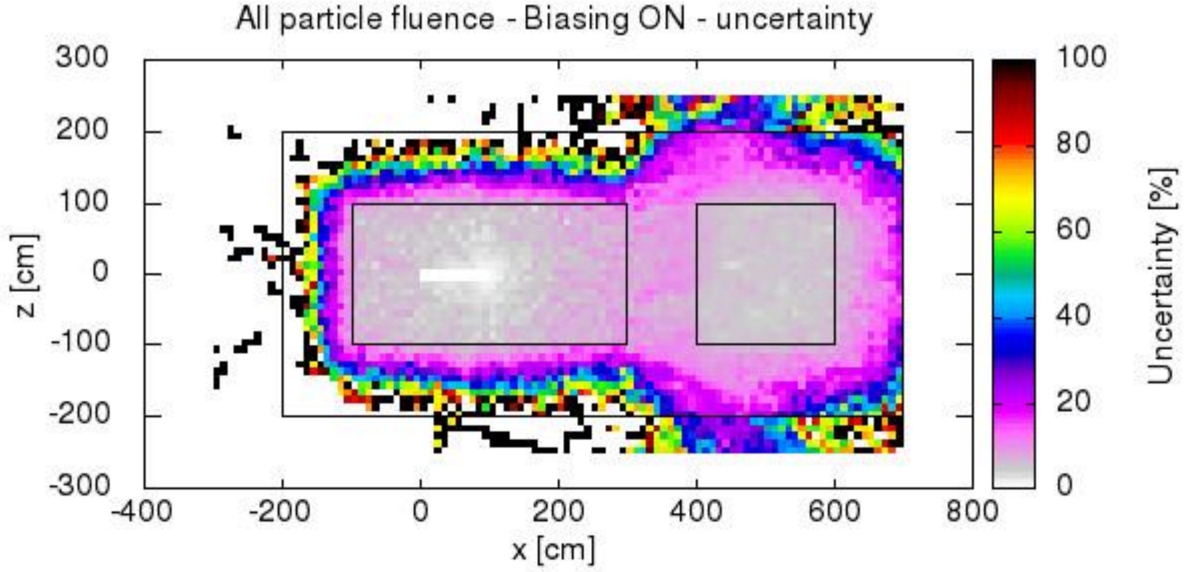
Characteristics

- Samples from distorted distributions
- Converges “quickly”

Drawbacks

- Cannot reproduce fluctuations and correlations
- Requires active reasoning and experience
- Requires user’s time to be implemented
- Incompatible with event-by-event scoring





Biasing techniques in FLUKA

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

During this lesson 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)
- Automatic Importance Biasing (**AUTOIMBS**)

SOON TO BE RELEASED!

Region Importance Biasing

Input card: **BIASING**

Region Importance Biasing

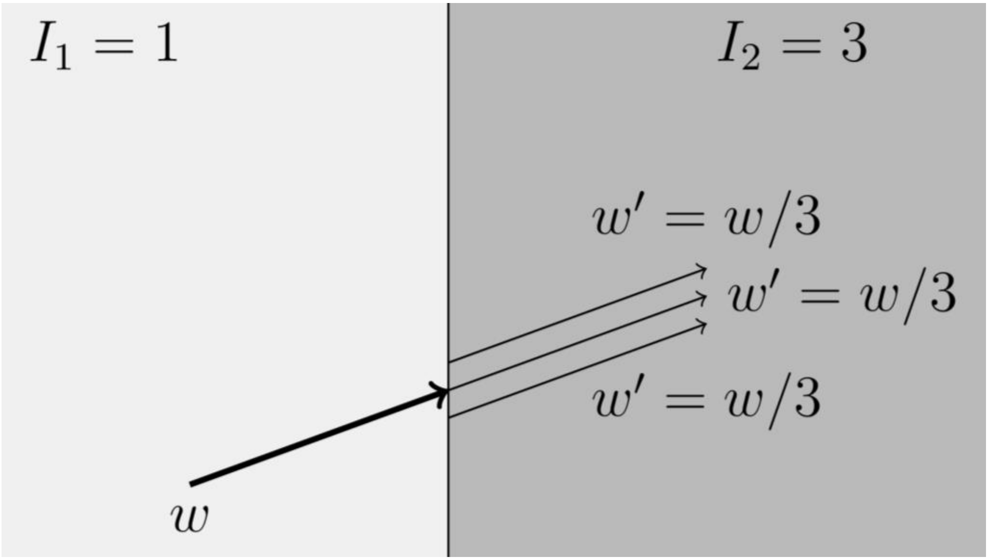
- Input card: **BIASING**
- Simplest form of biasing
- Applied when a particle crosses a region boundary (e.g. from Region1 to Region2)
- Based on *relative importance* of the two adjacent regions:

  $R = i_2/i_1$ = "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

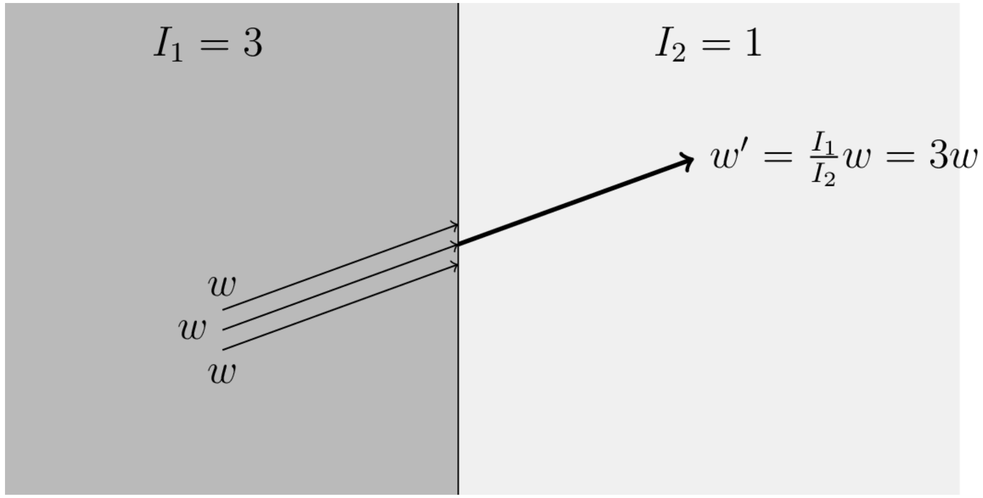
- Moving toward a higher importance region, *$R>1$*
- *$n = R = i_2/i_1$* particle *replicas* are created
- *Weight* of replicas is *$w = 1/R = i_1/i_2 < 1$*
- Total weight of all replicas is equal to the weight of the original particles
- FLUKA allowed values: *$5^{-1} \leq R \leq 5$*



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



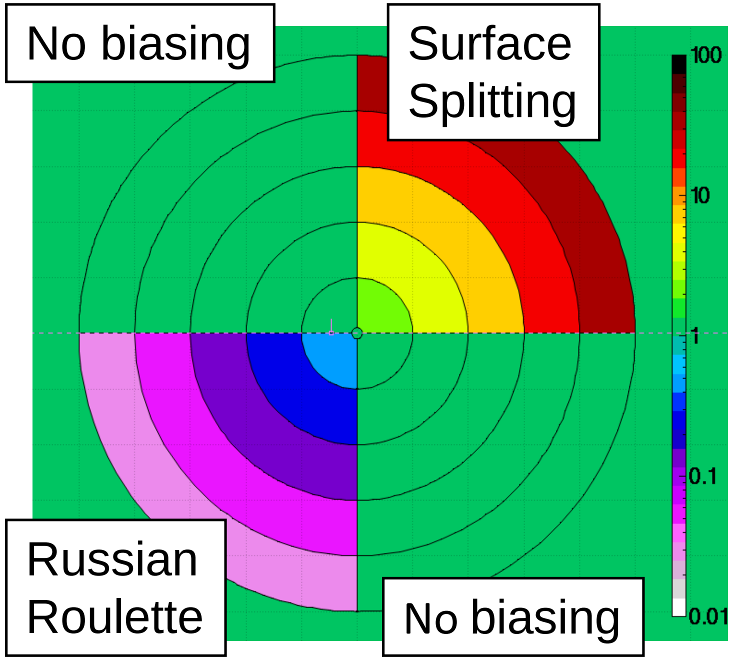
I : importance, w: particle weight
Particle survives with probability $I_2/I_1 = 1/3$
Surviving particle weight increased by $I_1/I_2 = 3$

Region Importance Biasing

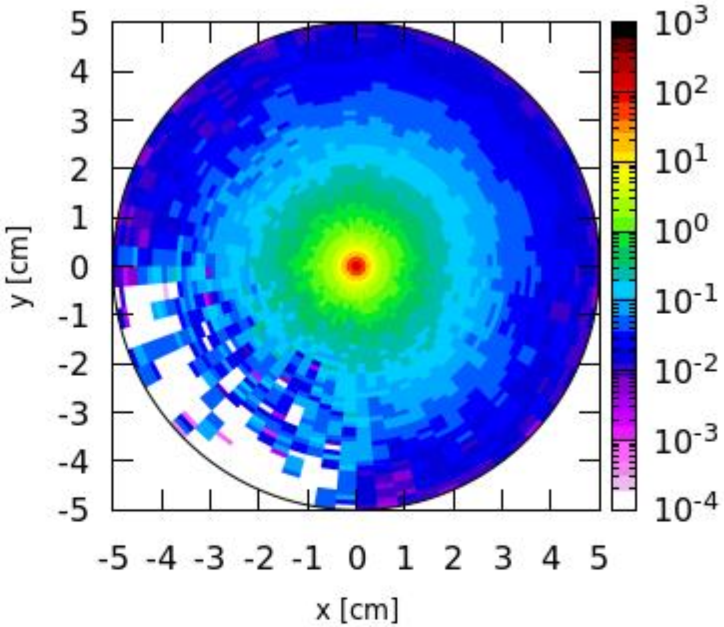
Example

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

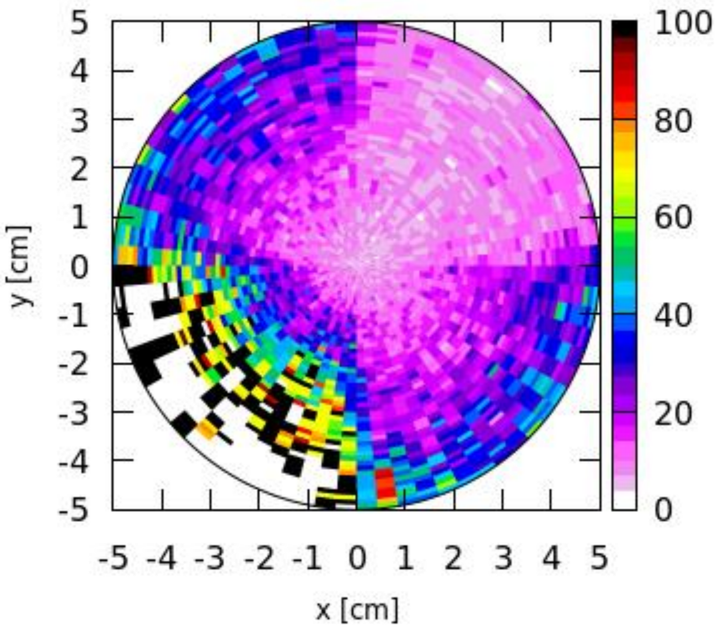
Region importance



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



Uncertainty on particle fluence [%]



Region Importance Biasing

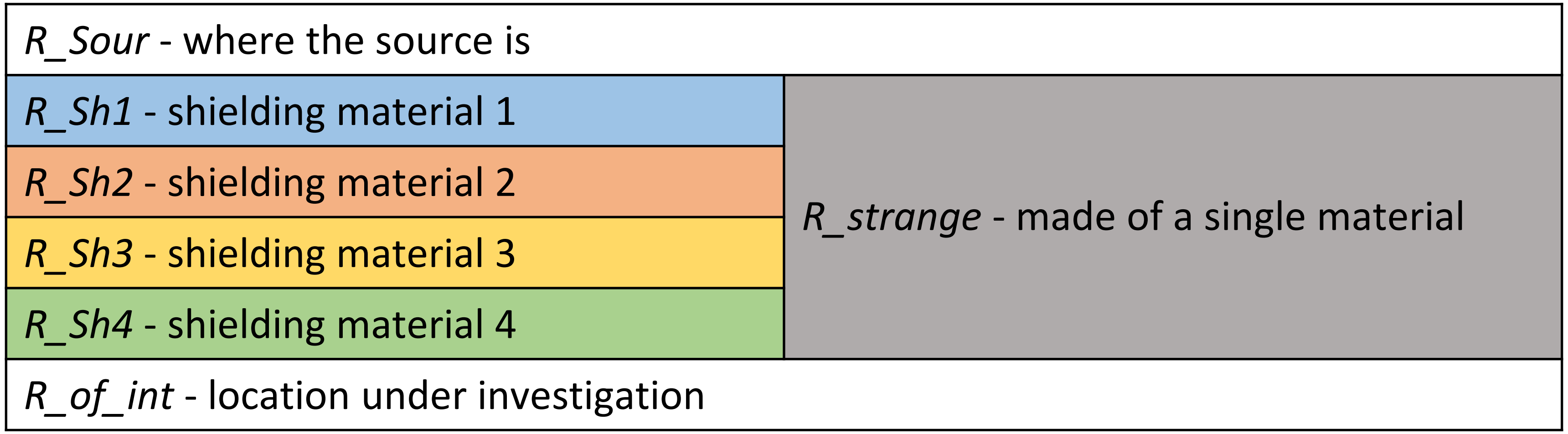
Drawbacks

- 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?



Region Importance Biasing

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  therefore, when crossing into a low density region (e.g. vacuum, air)
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- Could require geometry changes
  e.g: how to deal with a geometry like this?

<table>
<tr><td colspan="2">R_Sour - region_importance=1</td></tr>
<tr><td>R_Sh1 - region_importance=2</td><td rowspan="4">R_strange - region_importance=?</td></tr>
<tr><td>R_Sh2 - region_importance=4</td></tr>
<tr><td>R_Sh3 - region_importance=8</td></tr>
<tr><td>R_Sh4 - region_importance=16</td></tr>
<tr><td colspan="2">R_of_int - region_importance=32</td></tr>
</table>

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)

<u>Example explanation</u>:
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

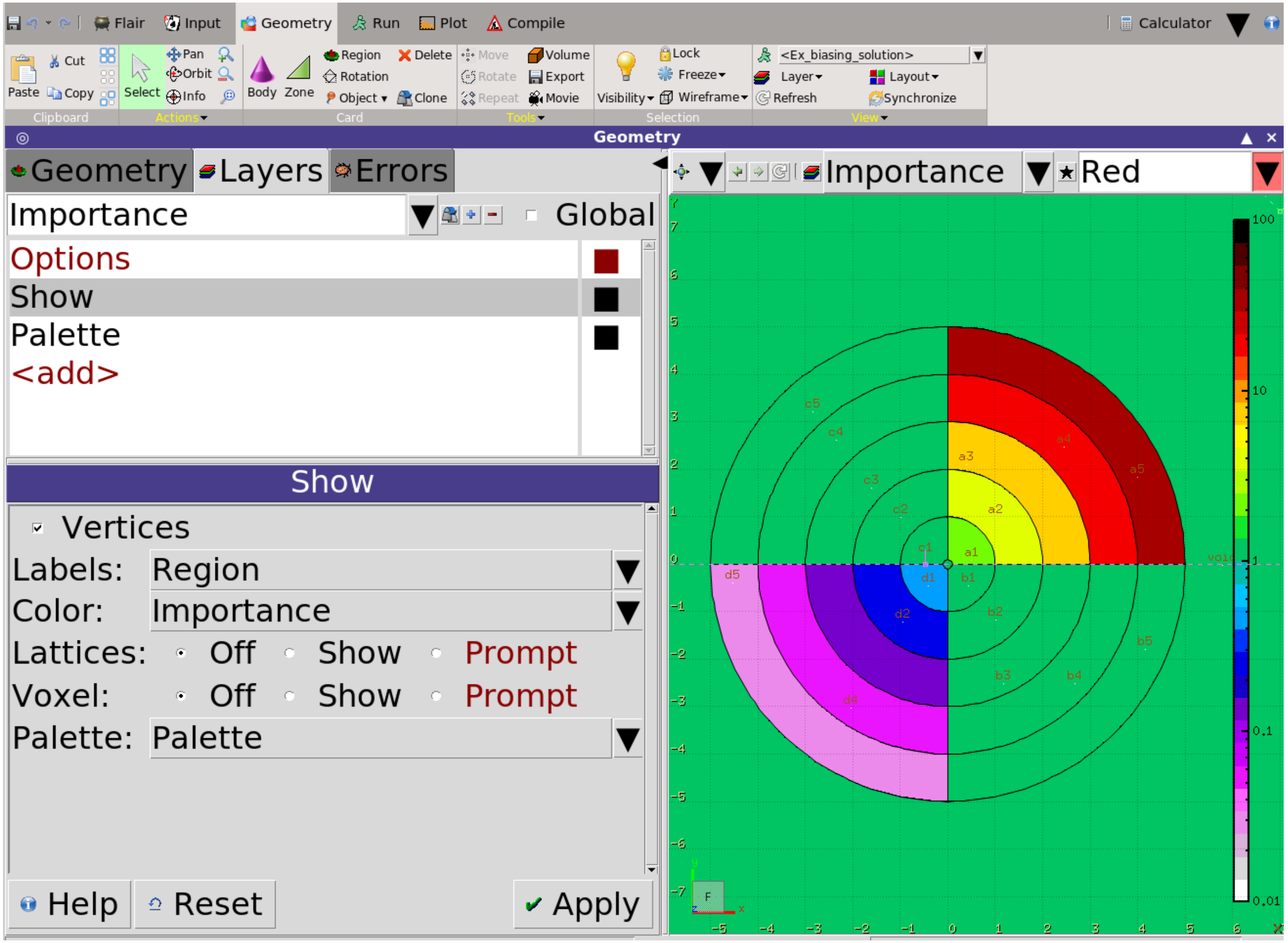
BIASING Type: **All regions ▾** Mod. M: **0**
Opt: ▾ Part: **PROTON ▾** to Part: **PROTON ▾** Step:

Region Importance Biasing - Digression

How to plot regions' importance?

- Create a dedicated layer
- In the "Show" panel select

  Color: "Importance"



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

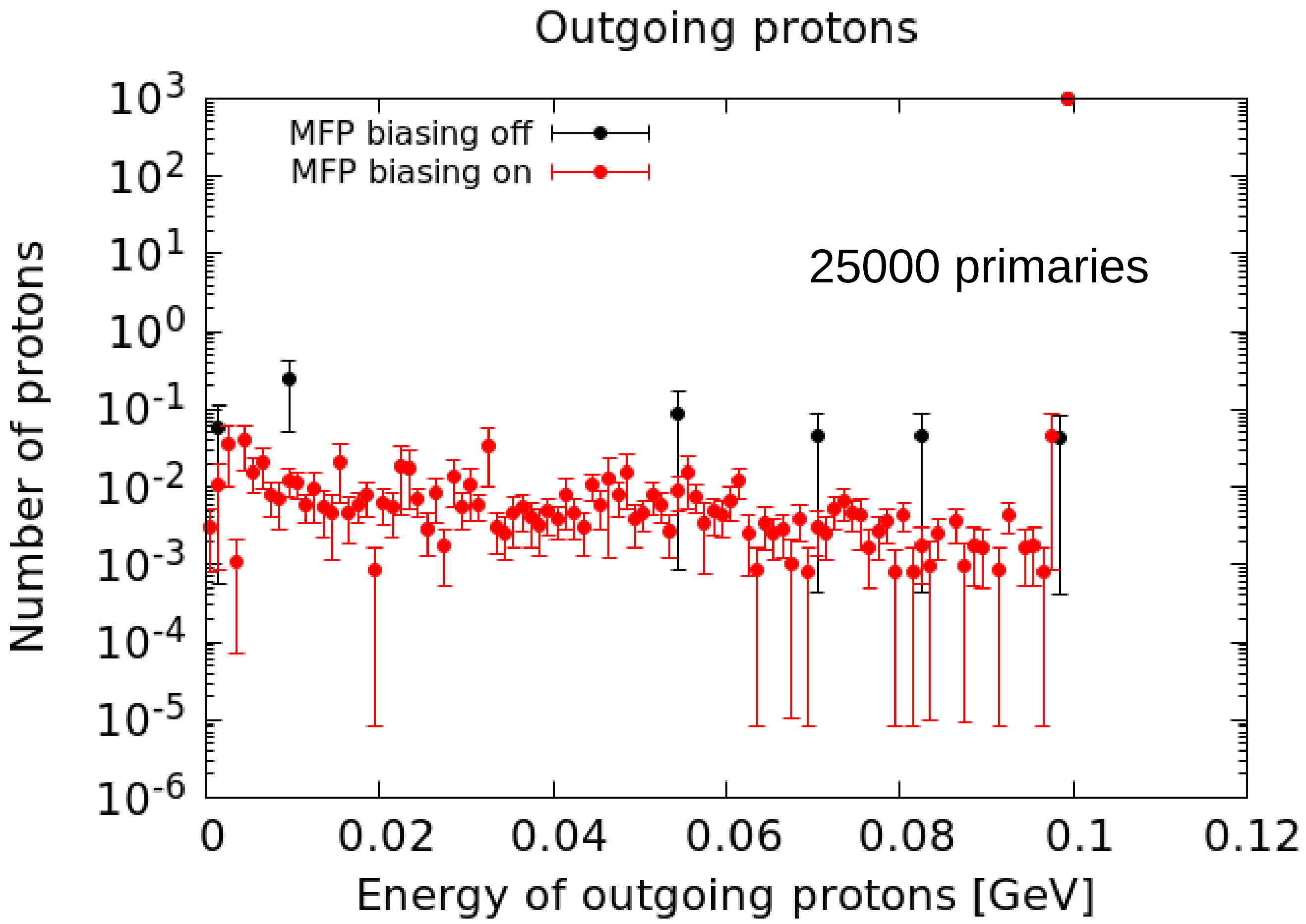
<u>Example explanation</u>:
Proton interaction length in *beryllium* is multiplied by a factor *correction factor=0.02* (reduced by a factor 50)

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

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- **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)

FLUKA