Normalisation modelling sources

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Geant 4

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Outline

- What / why ? Me?
- General concept
- Applied to specific domains
  - Accelerator
  - Space
- References

What / why ? Me ?

- Yes!
  - Almost all MC studies require this step
  - During simulation or, more likely, at post processing
- Absolute / relative values?
  - Whenever absolute → normalisation needed
- Method depends on
  - Source geometrical configuration &
  - Choices made in modelling the source

General concept

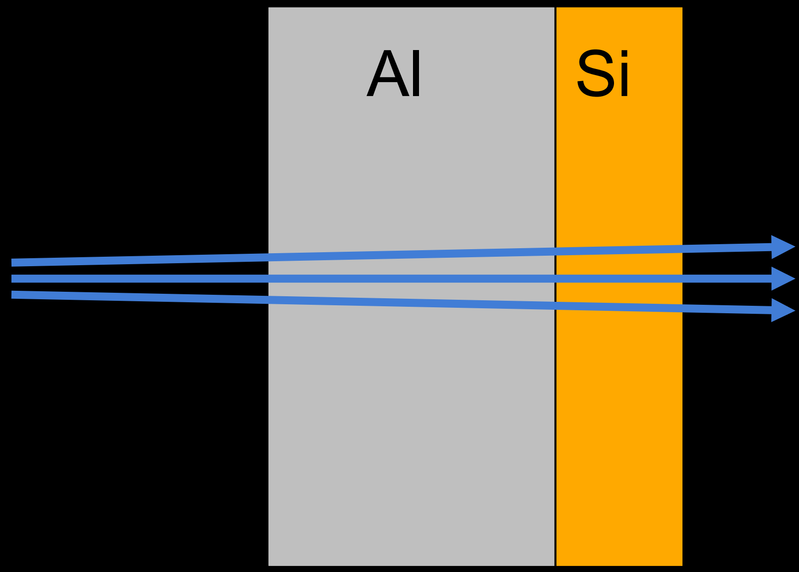
- Given a simulation quantitative result X_s (e.g. dose in a volume), the value expected in the real world X_r is obtained with a "rescaling"

N_s : # simulated events

N_r : # real events expected

- N_s is set by the user
  - Decision based on (statistical) error on estimates
- N_r depends on the real source
  - The source component which is modelled in the simulation world

Example 1
Beam irradiation



- Irradiation of shielded planar Si detector
- Parallel beam source, protons

- Final expected simulation results:
  - Average proton energy at Si
  - Total dose
  - Spectrum of event energy deposit

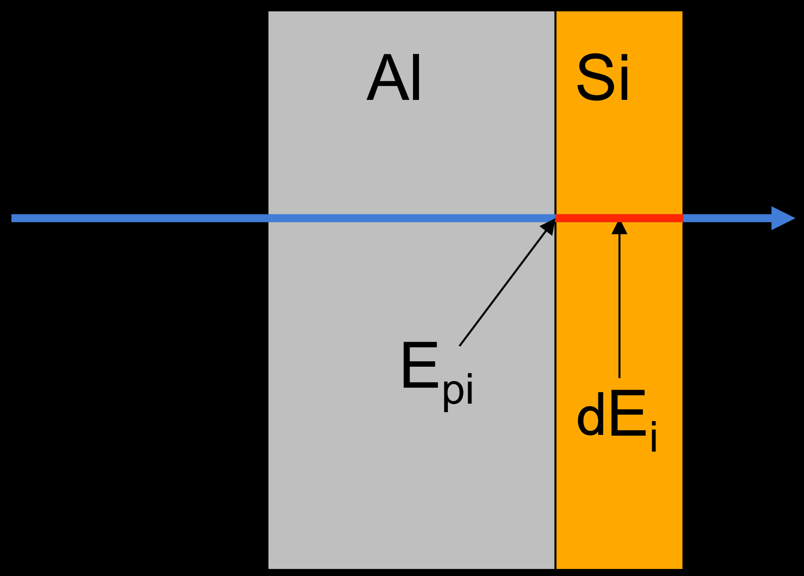
- GPS source description

```
/gps/particle proton

/gps/ene/type Gauss
/gps/ene/mono 400 MeV
/gps/ene/sigma 50. MeV

/gps/ang/type cos
/gps/ang/type beam1d
/gps/ang/sigma_r 5. deg

/gps/pos/type Beam
/gps/pos/shape Circle
/gps/pos/centre 0. 0. 0. mm
/gps/pos/radius 3. mm
/gps/pos/sigma_r .2 mm
```

Example 1
Normalisation

- Ns is set by the user
  e.g. Ns = 1.0E+05

- Nr is known
  e.g. Nr = 1.3E+11
  – Directly from beam monitor
  – Assuming beam profile fully contained in the geometry
    (if not → integrate flux over the SV surface)



Simulation results:

– Sum of proton energies

– Total energy deposit

– Histogram of event energy deposit

Normalised results:

– Average proton energy at Si
  (not a real normalisation)

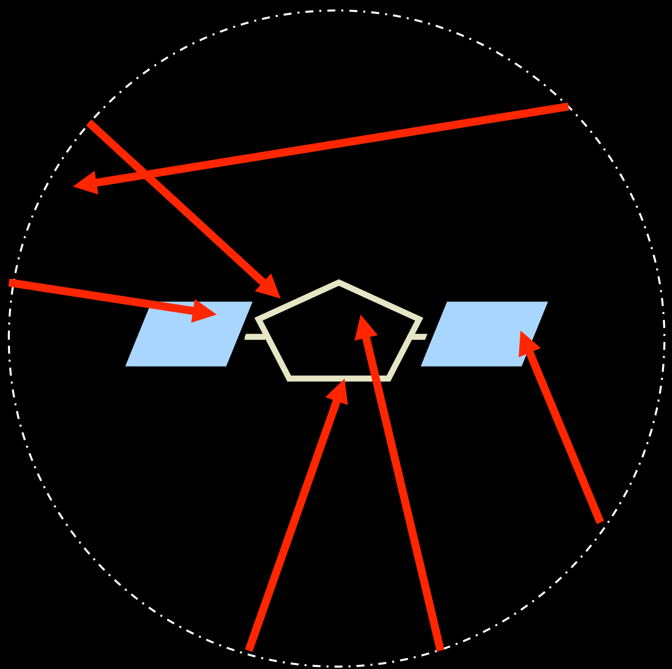
– Total dose

– Spectrum of event energy deposit

Example 2
Diffuse radiation in space

- Irradiation of satellite in space
- Isotropic source, electrons

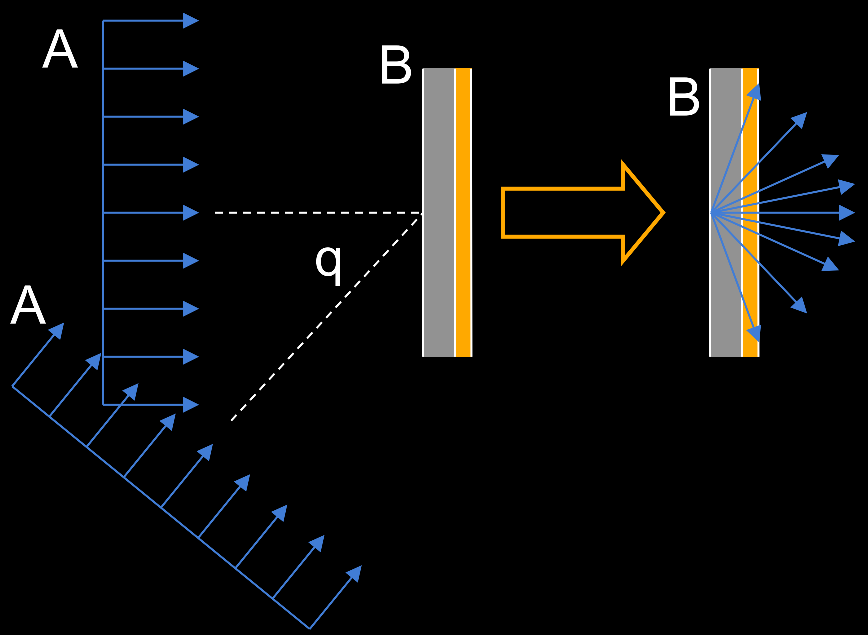
- Final expected results:
  - Total dose



- GPS source description

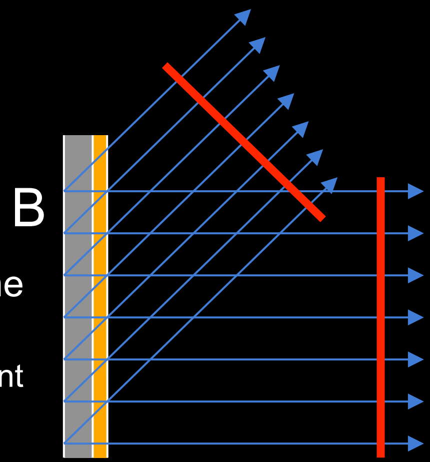
```
/gps/particle e-

/gps/ene/min 0.05 MeV
/gps/ene/max 1000 MeV
/gps/hist/point 0.05 0
/gps/hist/point 0.1 2100000000
/gps/hist/point 0.2 695000000
/gps/hist/point 0.3 372000000
/gps/hist/point 0.5 175000000
/gps/hist/point 1 60800000
/gps/hist/point 2 16300000
/gps/hist/point 3 6640000
/gps/hist/point 5 2030000
/gps/hist/point 10 383000
/gps/hist/inter Lin

/gps/pos/type Surface
/gps/pos/shape Sphere
/gps/pos/centre 0. 0. 0. cm
/gps/pos/radius 2.5 m

/gps/ang/type cos
```

Isotropic radiation in space
Cosine VS Isotropic ? I. Slab source



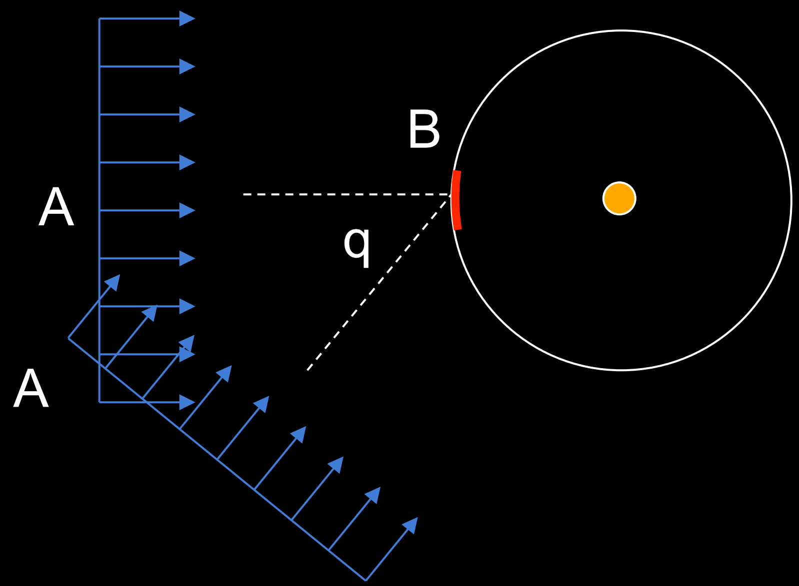
- Objective:
  model an isotropic flux in space, shooting from a planar surface (assuming flux from right is stopped)
- By definition of isotropic flux:
  → The flux passing through a surface (such as A) is not dependent on the direction
- The slab B sees
  - Full flux for a direction normal to its surface
  - reduced by a factor cos(q) for tilted directions (/cm^2 !)
  -

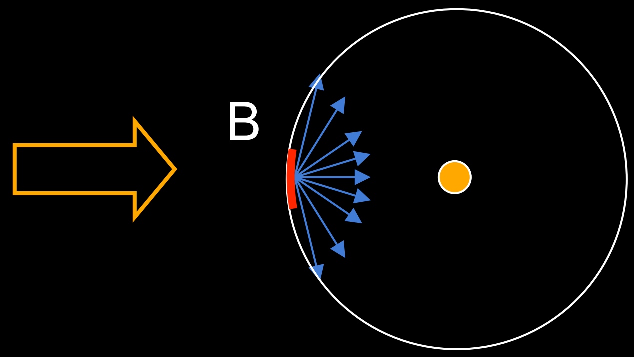
→ We must use "cosine-law" angular distribution when shooting primaries from the slab



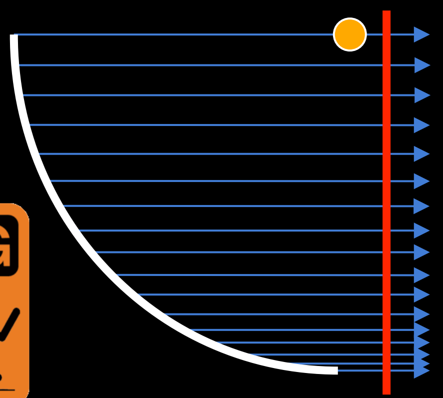
- If one shoots an isotropic flux from a slab the final distribution in space is not isotropic !
  - Different fluences through surfaces at different angles

Isotropic radiation in space
Cosine VS Isotropic ? II. Sphere source





- Same is valid for a spherical surface
  - the fluence for each direction is proportional to the cosine of the angle between the source direction and the local normal to the sphere surface
- Cosine-law angular emission actually works not only for the sphere, but for generic surfaces (e.g. shooting from a box)
- Isotropic angular emission from the surface leads to non isotropic fluence in the volume
  - E.g. for each emission direction the final distribution is not flat on a plane normal to the emission direction
- One can verify the various options by placing an oriented detector in different positions/ orientations in the volume



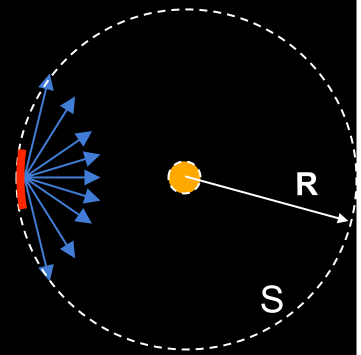
Example 2: Normalisation

- N_r is the number of particles traversing my source volume in the real world
- N_r depends on the external flux, integrated on relevant source surface and solid angle
  - Only the source geometry is relevant for source normalisation, no detector parameter

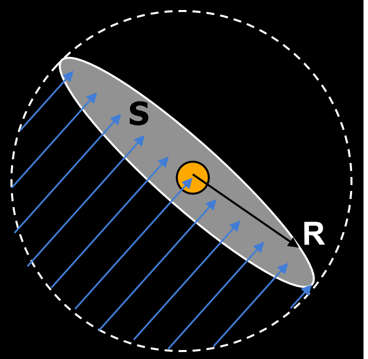
- F → external flux (energy integrated) [/ cm^2 s sr]

Two possible approaches

- Method 1
  - Integrate over the 2π emission angle, with cosine-law biasing →
  - Then integrate over the source sphere surface: $S = 4\pi R^2$



- Method 2 (euristic)
  - Assume isotropic source in space (no cosine-law) →
  - Take only sphere equatorial surface as effective geometrical cross section: $S = \pi R^2$

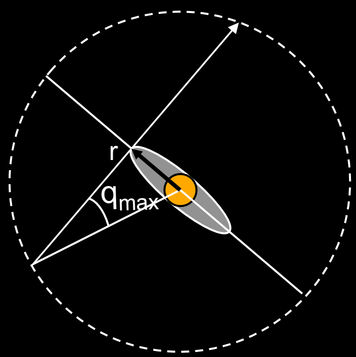


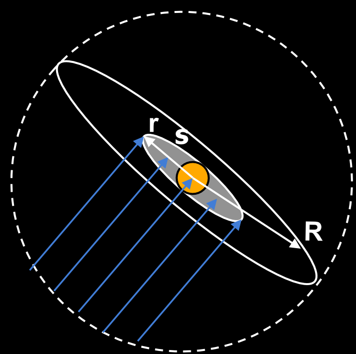
Sphere case: limiting the emission angle

- Modelling isotropic sources in space, one may want to limit the max emission angle to $q<q_{max}$ (source biasing)
  - Method 1: $N_r = F \quad (p \sin^2 q_{max}) \; (4p\, R^2) \; = \; F\, 4\, p^2\, R^2 \sin^2 q_{max}$
  - Method 2: $N_r = F \quad (4p) \;\; s = F \quad 4p \quad (pr^2) \; = \; F\, 4\, p^2\, R^2 \sin^2 q_{max}$

- In case $q_{min} < q < q_{max}$ → $N_r = F\, 4\, p^2\, R^2 (\sin^2 q_{max} - \sin^2 q_{min})$

- The effect is like a reduction of the effective relevant cross-section surface





Summary

- Number of simulation events does not have to match the number of particles in the real world
  - N_s driven by statistical error on estimates
  - Final results are then normalised

- Given a simulation quantitative result D_s (e.g. Dose in a volume), the real value expected in space D_r is generally obtained with the rescaling
  $D_r = D_s (N_r / N_s)$

- N_r depends on the external flux, integrated on relevant surface and solid angle and depends on
  - Source geometrical configuration &
  - Choices made in modelling the source

Useful references

- J.D. Sullivan, NIM 95 (1971) 5-11

NUCLEAR INSTRUMENTS AND METHODS 95 (1971) 5–11; © NORTH-HOLLAND PUBLISHING CO.

GEOMETRICAL FACTOR AND DIRECTIONAL RESPONSE OF SINGLE AND MULTI-ELEMENT PARTICLE TELESCOPES*

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- CREME 86 manual
- PDG (full version) on Cosmic-Ray