GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

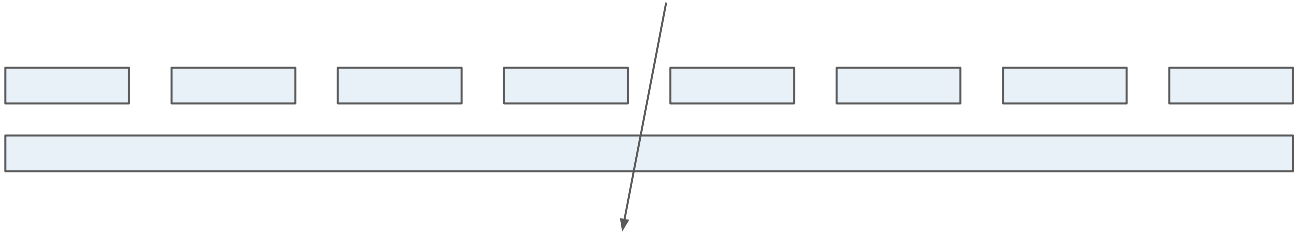
Hermeticity study comparing trapezoidal and rectangular scintillation bars for the HERD PSD

Andrea Parenti and Leandro Silveri
on behalf of the GSSI group

03 / 05 / 2021

Hermeticity study

- **Aim of the study** :
  - Due to the wrapping around the bars there will be **gaps** between the active scintillating volumes.
  - This will lead to **inefficiencies** for the photon veto system.
  - **Geometrical layout**: two planes with bars oriented in X and Y directions.
  - Compare hermeticity between bars with rectangular and trapezoidal shape.
  - Overall comparison between 5 layouts.

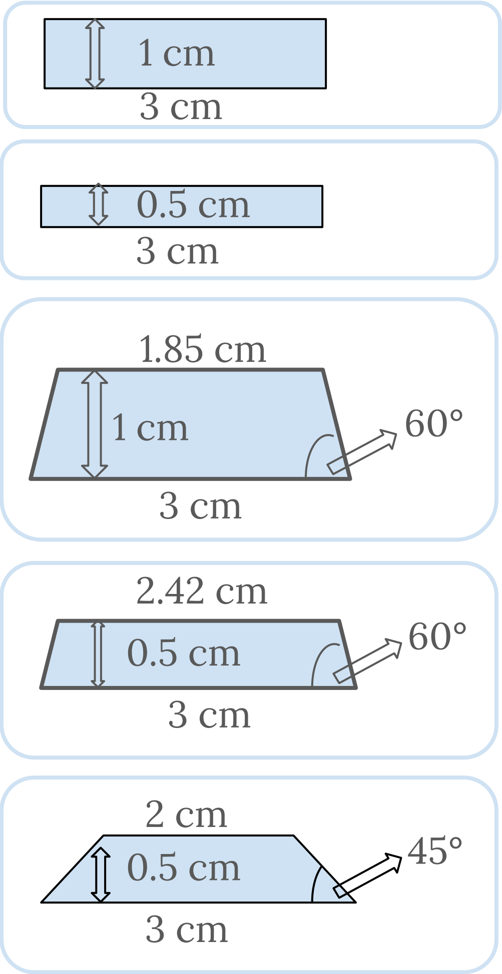


Layouts

- **Rectangular bars**:
  - 50 x 3 x 1 cm^3
  - 50 x 3 x 0.5 cm^3
    - 15 bars per layer, 1.5mm wrapping

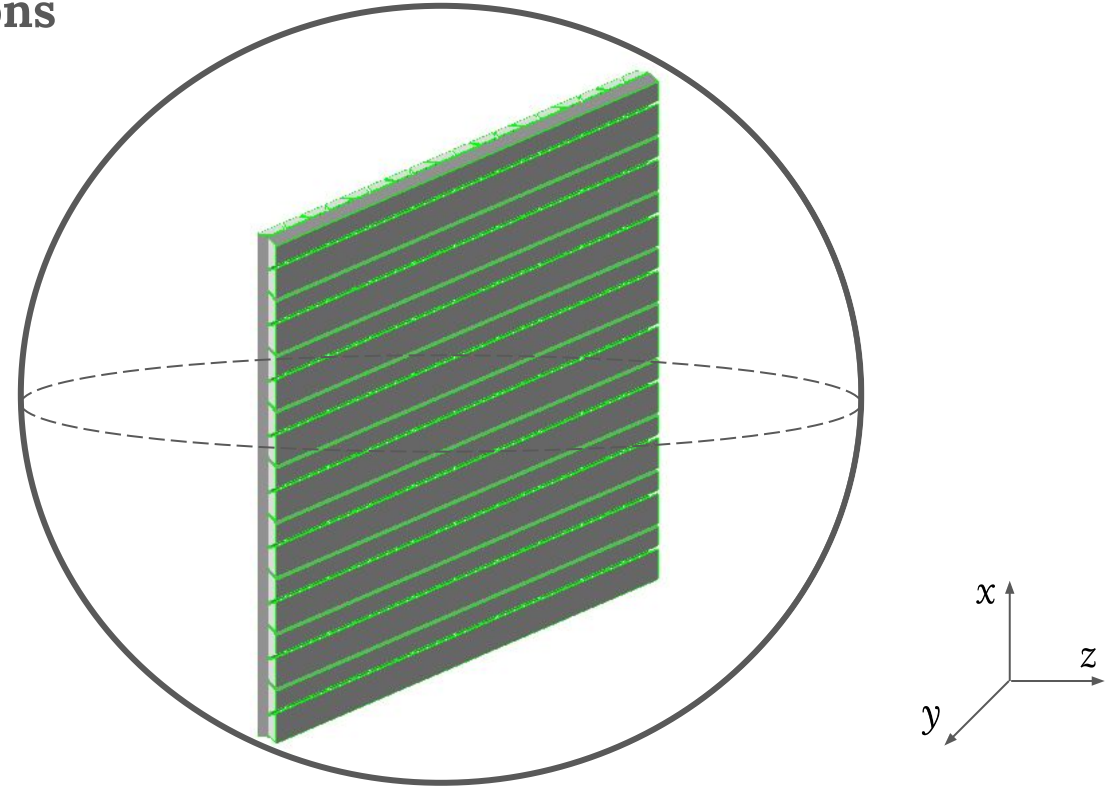
Conservative thickness

- **Trapezoidal bars**:
  - *Length*: 50 cm *Height*: 1 cm *Angle*: 60°
    - 18 bars per layer, 1.5 mm wrapping
  - *Length*: 50 cm *Height*: 0.5 cm *Angle*: 60°
    - 16 bars per layer, 1.5 mm wrapping
  - *Length*: 50 cm *Height*: 0.5 cm *Angle*: 45°
    - 17 bars per layer, 1.5 mm wrapping



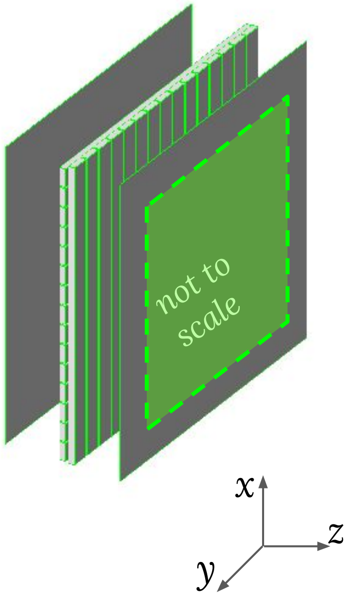
Beam

- Generate particles on a **spherical surface** of **30 cm** radius.
- Particles are generated with **isotropic** direction, going inwards.
- **100 GeV protons**
- **10M** events



Event selection

- Add two "geometrical" planes, parallel to the array:
  - 50 cm x 50 cm x 1 μm
  - G4_Galacitc, material with $\varrho = 10^{-24}$ g/cm^3
  - Placed 1.5 mm above and below the array
- Consider only primaries crossing **40x40 cm^2** geometrical plane to avoid border effects.
- Tag events in which the primary crosses both geometrical planes.
- Tag events in which the primary crosses both geometrical planes & no PSD bar ("***missing primaries***").



- Compute **percentage losses** as ratio between missing primaries and overall primaries impinging on the geometrical planes.

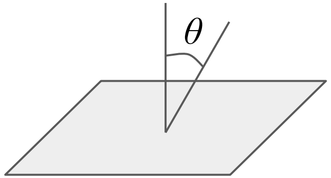
Efficiency: overall counts

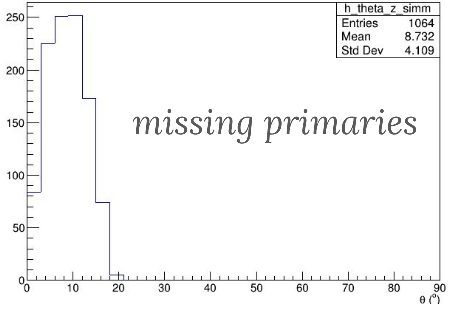
Layout	2 planes	2 planes + 2 scint layer	2 planes + 0 scint layer	ε_{loss} (%)	ε_{loss} improvement
Rect - 1 cm	2'397'002	2'327'024	651	**0.027 ± 0.001**	**-**
Trap - 1 cm - 60°	2'400'098	2'092'048	583	**0.024 ± 0.001**	**-11%**
Rect - 0.5 cm	2'563'996	2'429'218	2141	**0.084 ± 0.002**	**-**
Trap - 0.5 cm - 60°	2'563'780	2'109'878	1958	**0.076 ± 0.002**	**-10%**
Trap - 0.5 cm - 45°	2'562'896	2'132'491	1789	**0.070 ± 0.002**	**-17%**

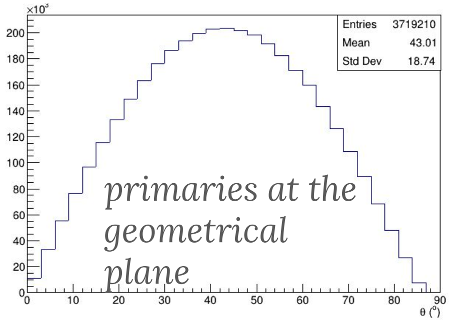
- Percentage of losses around 2×10^{-4} - 8×10^{-4} with 1.5 mm wrapping.
- Best option overall is trapezoidal bar, 1 cm tall, 60° angle.
- Between the 0.5 cm thick bars, best option is trapezoidal bar with 45° angle.

Efficiency as a function of the impinging angle (θ)

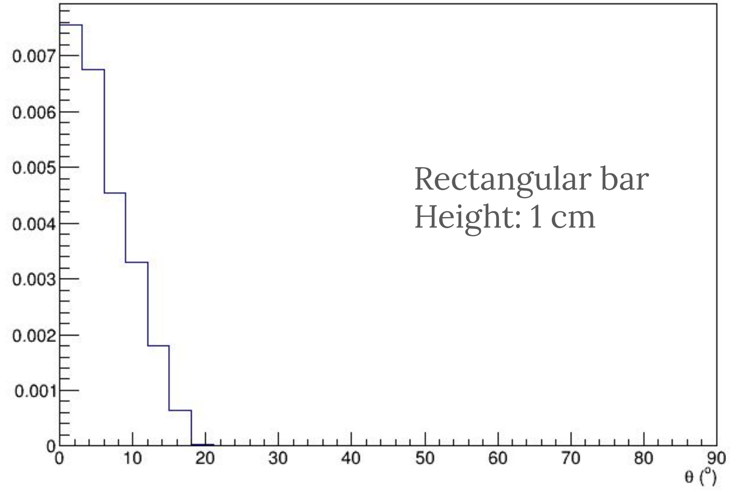
- With the real experiment the event selection will restrict the angular distribution: look also at the efficiency as a function on the angle.





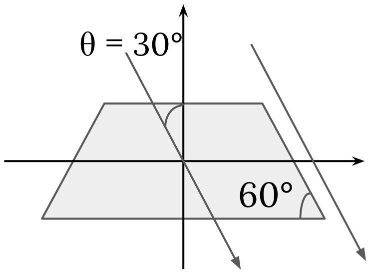


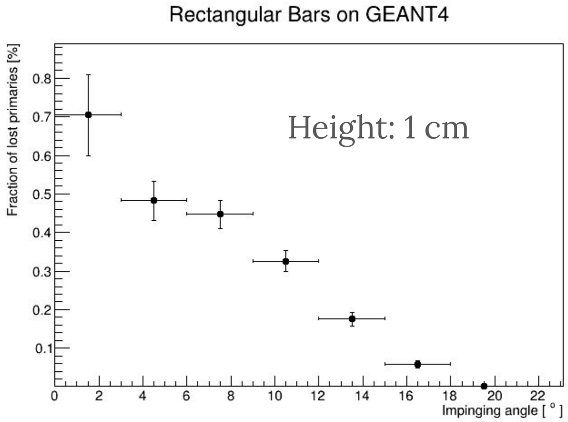
Fraction of missing primaries as a function of the impinging angle

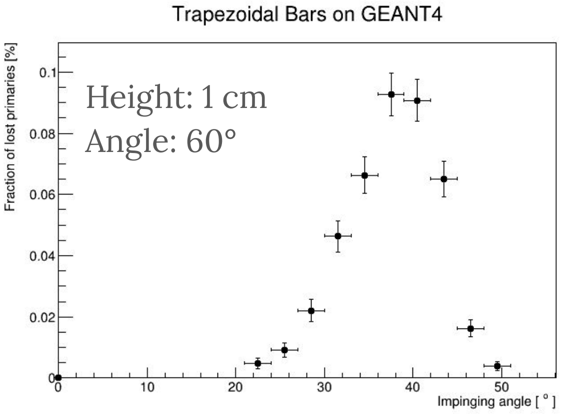


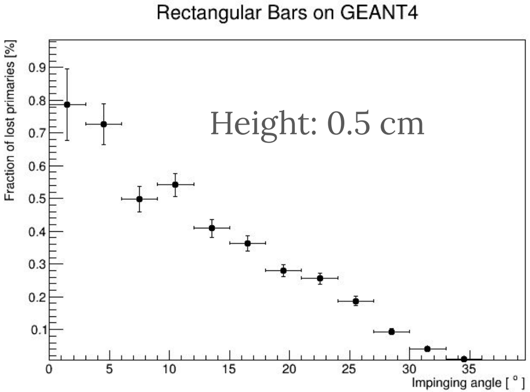
- Normalize number of missing primaries to number of primaries impinging on the geometrical plane, per unit angle.

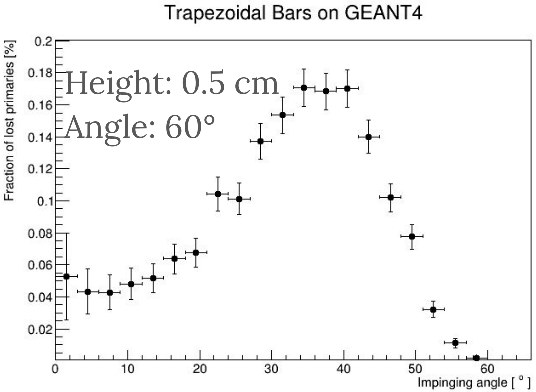
Efficiency as a function of the impinging angle (θ)

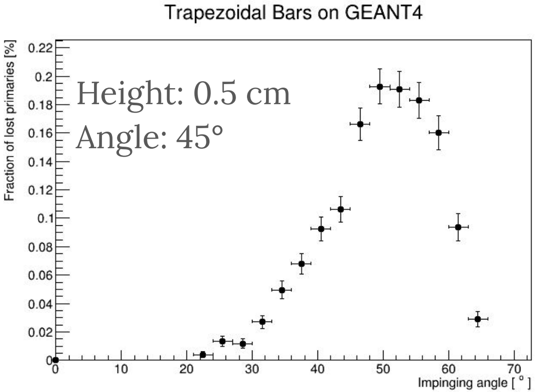








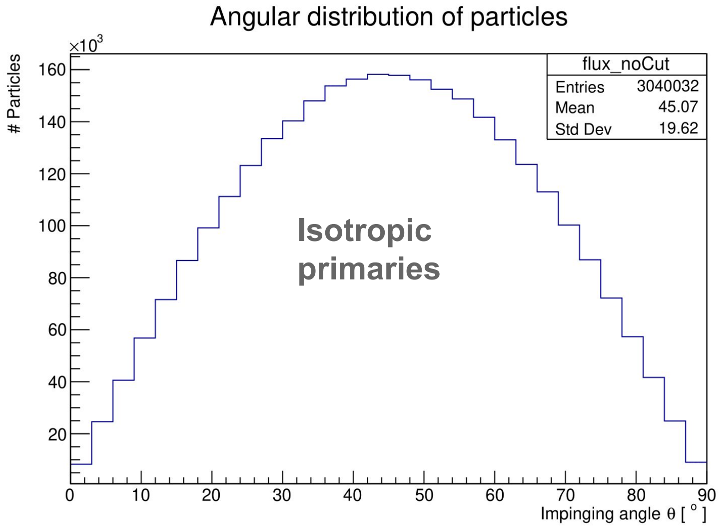


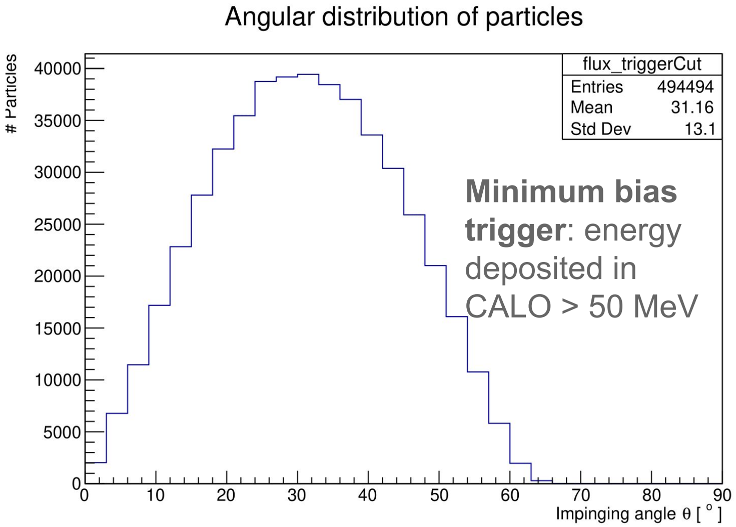


- Trapezoidal shape has losses at angles far from the vertical.

Angular distribution "folding"

- To better simulate the HERD geometrical acceptance, look at **HerdSoftware** angular distribution of impinging primaries with minimum bias trigger request.





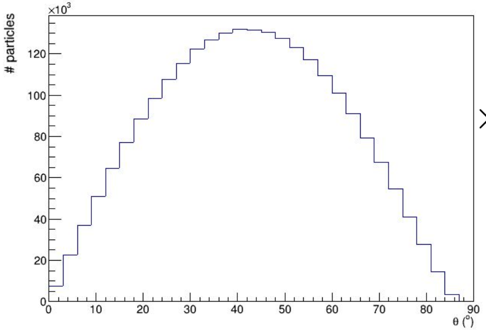
- Divide bin by bin to get some "folding factors":

$$F(\theta_i) = \frac{trigCut \rightarrow Entries(\theta_i, \theta_i + \Delta\theta_i)}{noCut \rightarrow Entries(\theta_i, \theta_i + \Delta\theta_i)}$$

“Folded” histograms

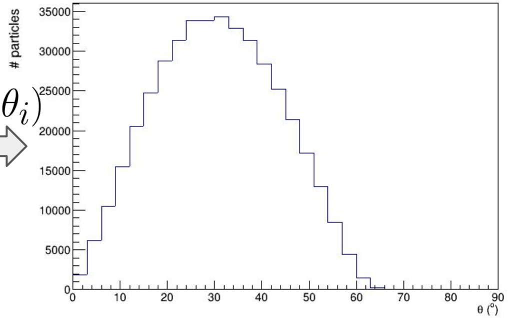
- Reweight angular distribution histograms by multiplying entries of i-th bin by folding factor $F(\theta_i)$.

Primaries at the geometrical plane



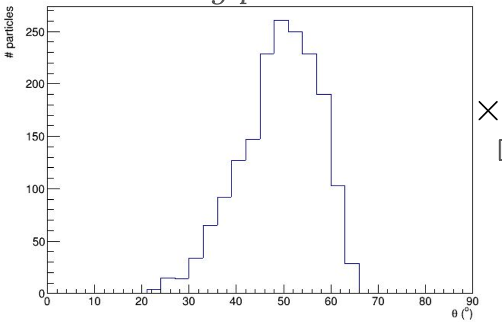
$\times F(\theta_i)$

Primaries at the geometrical plane



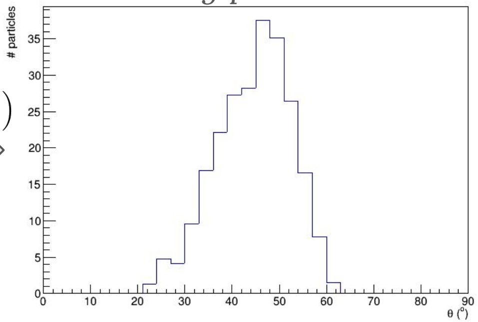
Maximum of the angular distribution shifts from 45° to ~30°

Missing primaries



$\times F(\theta_i)$

Missing primaries



Trapezoidal bars
0.5 cm tall
45° angle

Efficiency after "folding"

- Compute overall losses after folding as:

$$\varepsilon_{loss} = \frac{\#\text{ entries missing primaries (wFolding)}}{\#\text{ entries total primaries (wFolding)}}$$

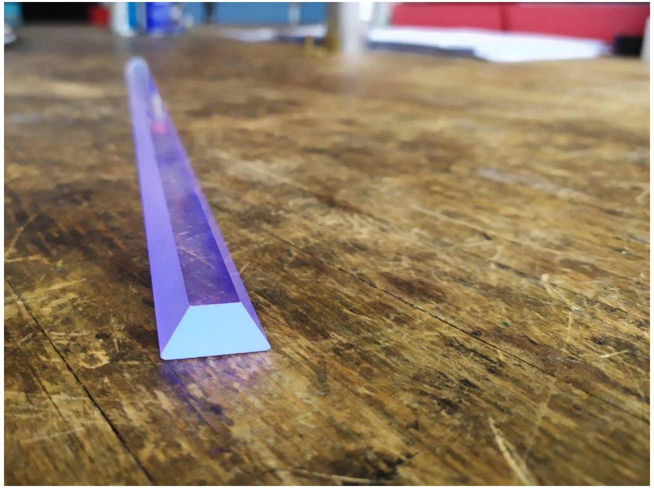
Layout	ε_{loss} (%)	ε_{loss} *wFolding* (%)	ε_{loss} *improvement*
Rect - 1 cm	**0.027 ± 0.001**	**0.045 ± 0.003**	**-**
Trap - 1 cm - 60°	**0.024 ± 0.001**	**0.032 ± 0.003**	**-29%**
Rect - 0.5 cm	**0.084 ± 0.002**	**0.148 ± 0.006**	**-**
Trap - 0.5 cm - 60°	**0.076 ± 0.002**	**0.108 ± 0.005**	**-27%**
Trap - 0.5 cm - 45°	**0.070 ± 0.002**	**0.054 ± 0.004**	**-63%**

- Percentage of losses ranging from $3\text{x}10^{-4}$ - $1.5\text{x}10^{-3}$.
- Folding lowers losses for trapezoidal bar, 45°. More requests for shower containment in the calorimeter will modify the angular distribution even further.

Conclusions

- Study of hermeticity of scintillation bar array, comparing rectangular and trapezoidal shapes.
- 5 different layouts simulated and compared.
- A “folding” was performed with the help of a HerdSoftware simulation to take into account the detector CALO requests.

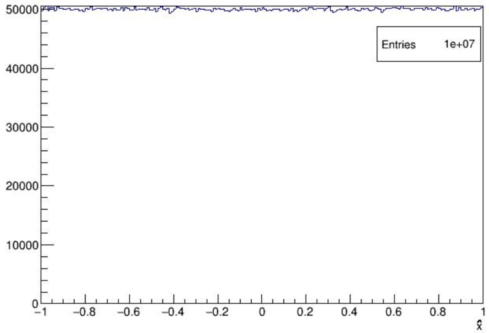
- **Results**:
  - Best among 0.5 cm tall bars: **trapezoidal shape, 45° angle** with losses of $5\mathrm{x}10^{-4}$ compared to rectangular shape with $1.5\mathrm{x}10^{-3}$ losses.
- Same approach could be used for tiles.

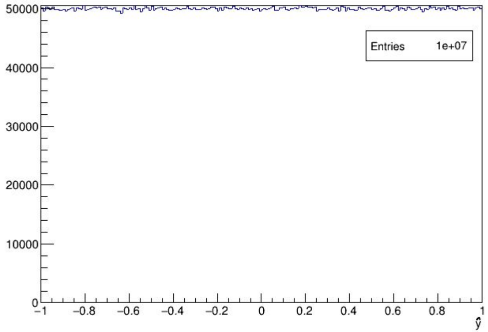


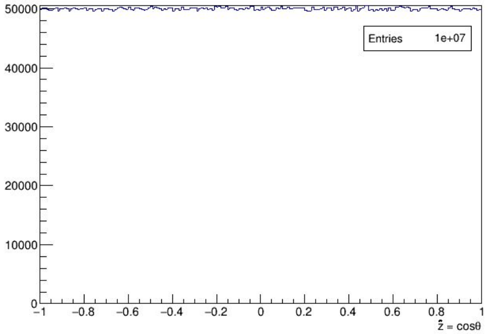
Backup slides

Primary particle direction

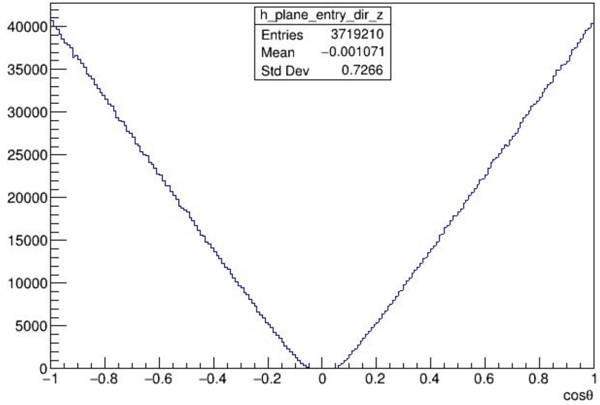
Direction at generation: uniform in cosθ

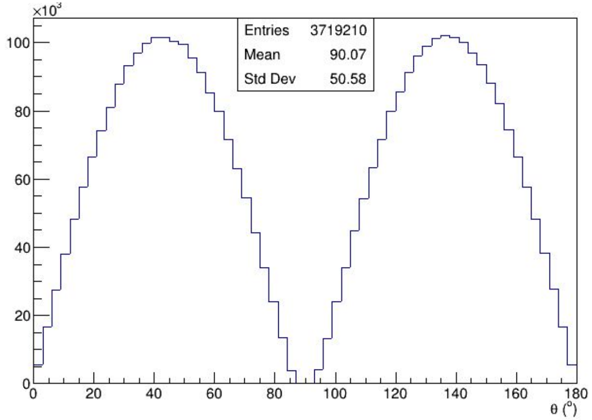






Direction at the geometrical plane (xy plane)





Impinging angle: comments

- Isotropic flux passing through a plane: “cosine law”

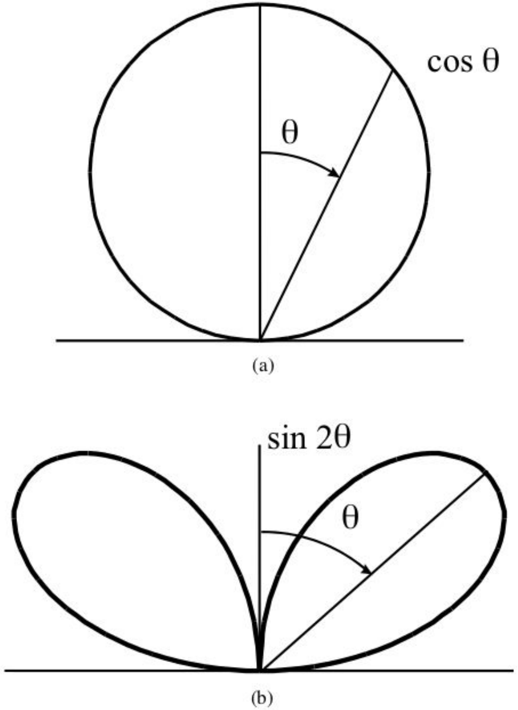


Fig. 2. (a) Projection through the cosine distribution of molecular flux; (b) the polar angular-probability distribution associated with a cosine distribution of molecular flux.

5. Incorrect interpretation of the cosine distribution law

The most common misunderstanding associated with the cosine law arises when it is *erroneously* supposed to state that:

> the probability of a molecule leaving the surface within a narrow angle $d\theta$, in a direction making an angle θ to the surface normal, is $\cos\theta$.

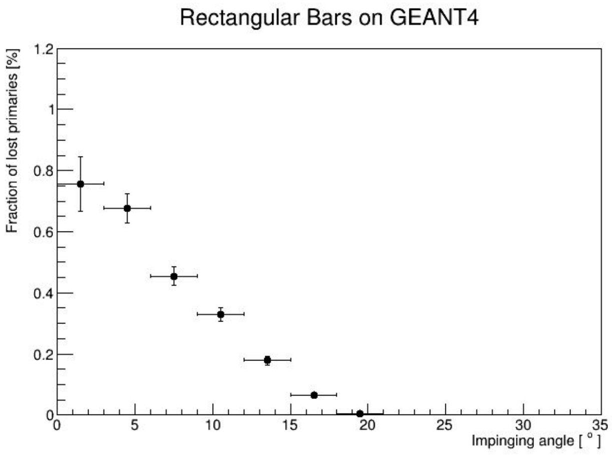
The misinterpretation occurs most often when a system is being modelled in two dimensions. The traditional schematic representation of the cosine law for molecules scattered from a surface is shown in Fig. 2(a). Occasionally this is misinterpreted as being the *polar angular-probability distribution* whereas in fact it is a projection through the *molecular flux distribution*. The actual polar angular-probability distribution is shown in Fig. 2(b).

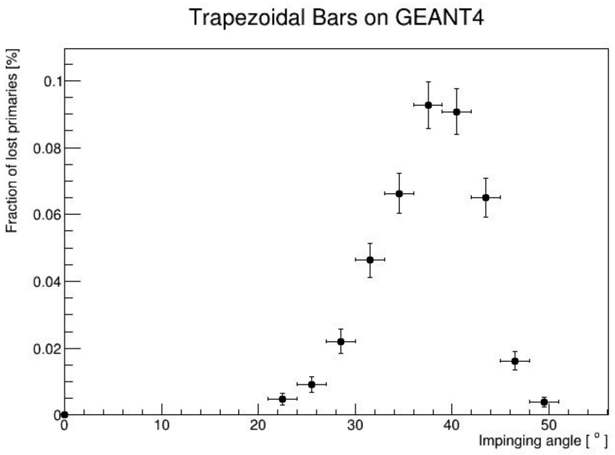
The *incorrect* statement of the cosine law fails to take into account the three-dimensional nature of the molecular distribution and the inherent fact that the solid angle $d\Omega$ between θ and $\theta + d\theta$ is a function of θ namely $2\pi\sin\theta\, d\theta$.

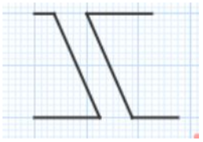
- Taken from: [The correct and incorrect generation of a cosine distribution of...]
- Another related paper: [A geometric factor calculation method based on the isotropic flux assumption]

Efficiency as a function of the impinging angle (θ)

Height: 1 cm







Height: 0.5 cm