Tumulus @ LAPP

Maximilien Chefdeville, Corinne Goy & Yannis Karyotakis
+ Sabine Elles

Status of the software and perspectives

Some acceptance studies

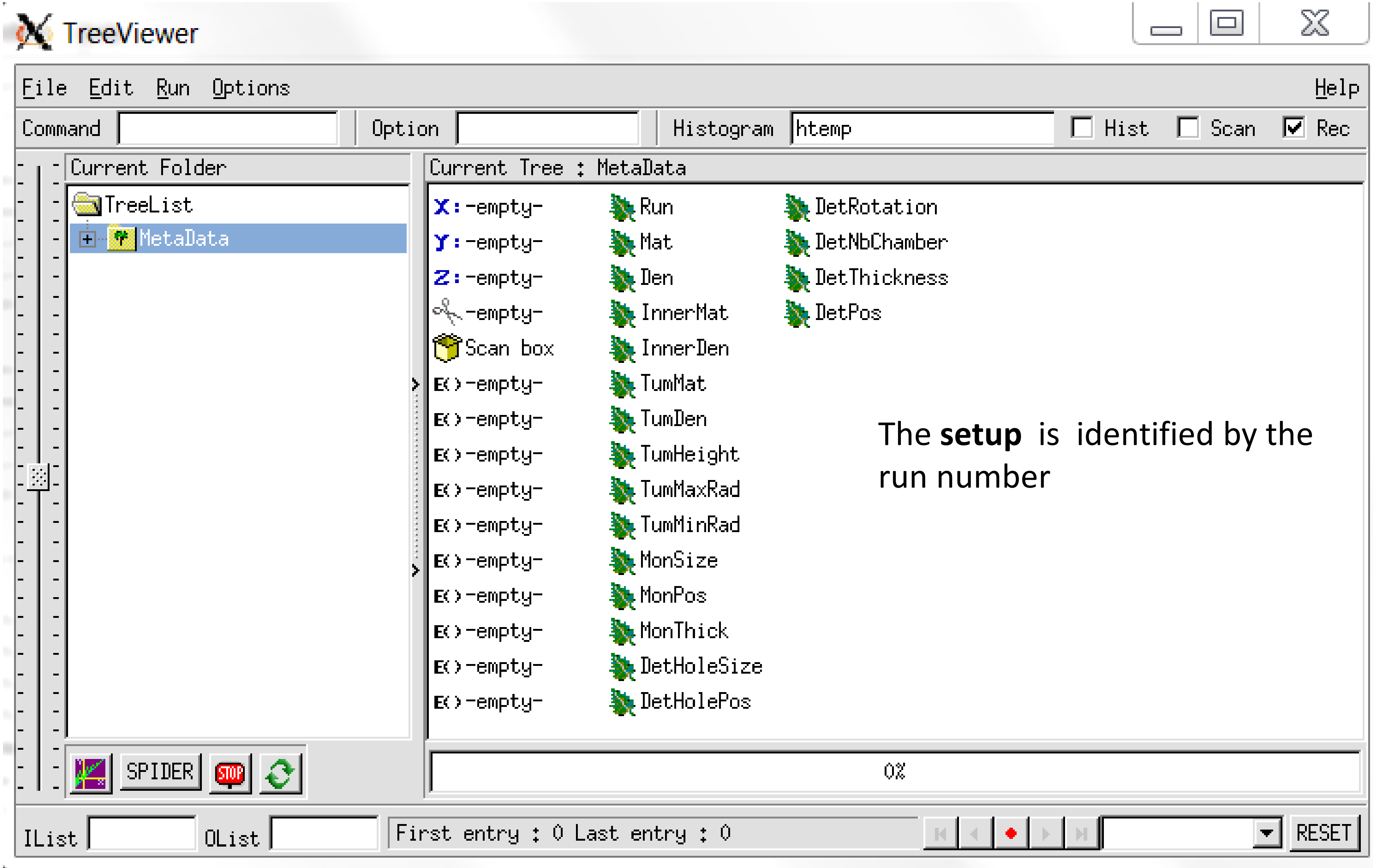
Reminder

- Geant4 based software
- Located :
  - https://lapp-svn.in2p3.fr/subversion/groups/lc/Tumulus

Status of the software

- Versatile setup where the geometry can be parametrized
  - Tumulus
    - Dimensions
    - Material (density)
  - Monument
    - Dimensions
    - Position
    - Material
  - Detector
    - Dimensions
    - Position / Orientation
    - Nb of chambers/detectors

Too versatile ! -> MetaData ntuple



The **setup** is identified by the run number

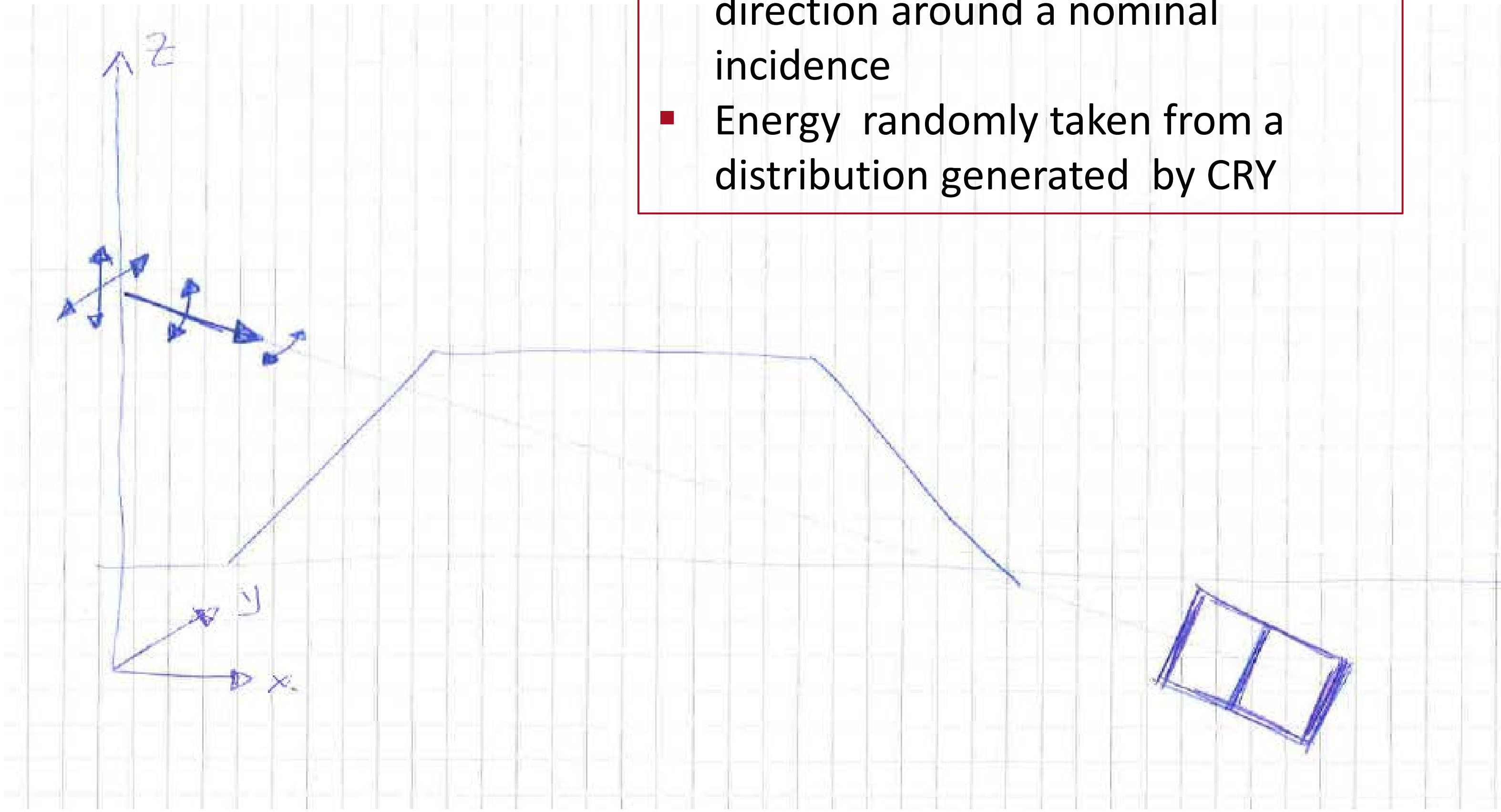
Other (rather) recent additions

- Sensitive detector was added
  - Allows to perform a “digitization” with PadSize 1cm
  - (to add noise, attenuation etc)

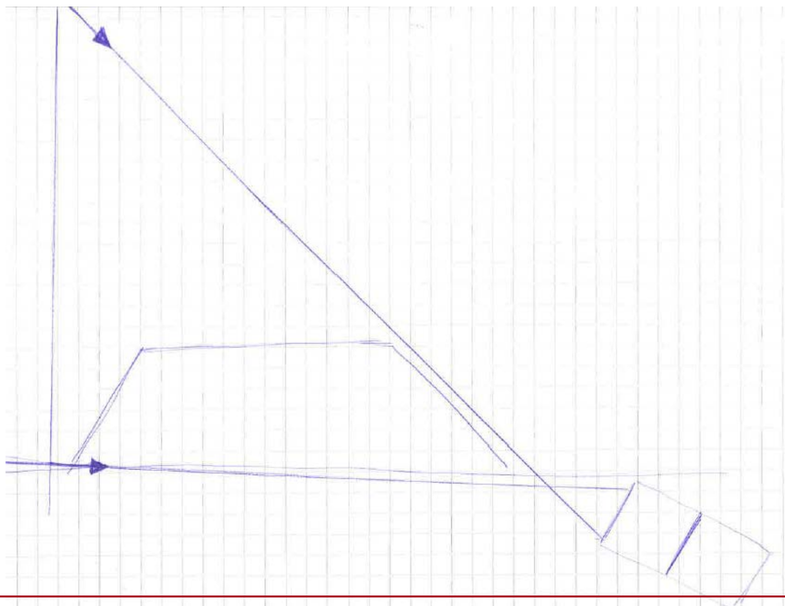
- PrimaryGeneratorAction
  - Several option available from data cards
    - Monokinetic – pointing to the detector
    - A la “Yannis”
    - A la “Corinne”
    - Interface to CRY generator
    - Acceptance (see later)

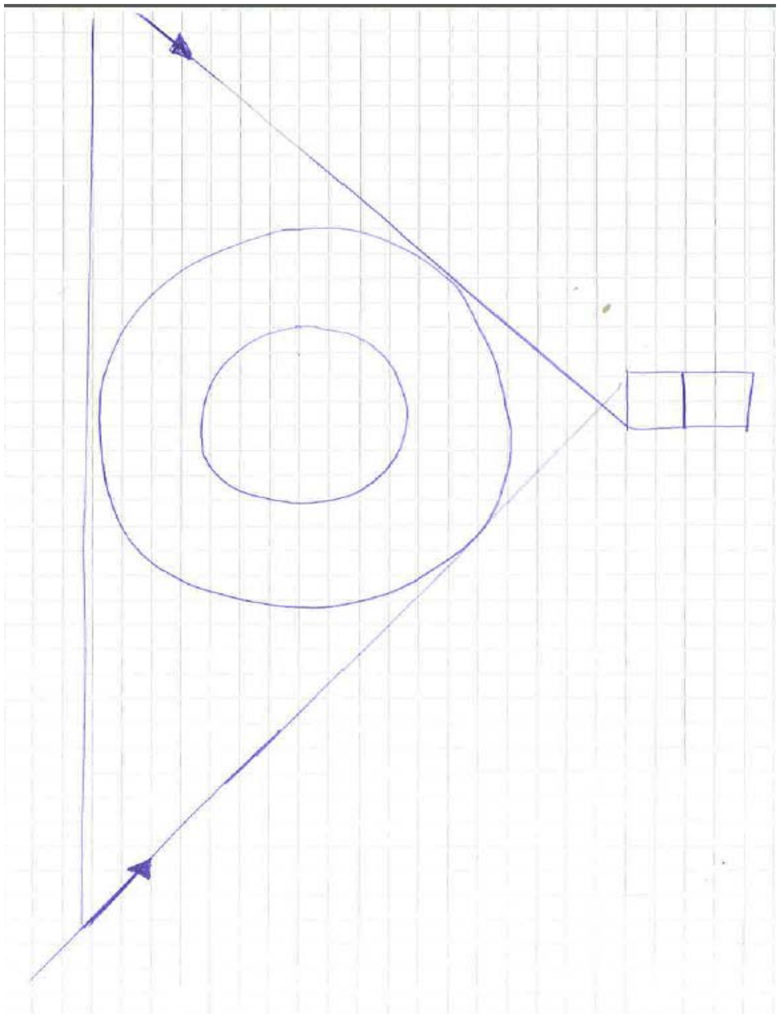
A la "Yannis"

- Random smearing in Z, Y and direction around a nominal incidence
- Energy randomly taken from a distribution generated by CRY



A la “Corinne”

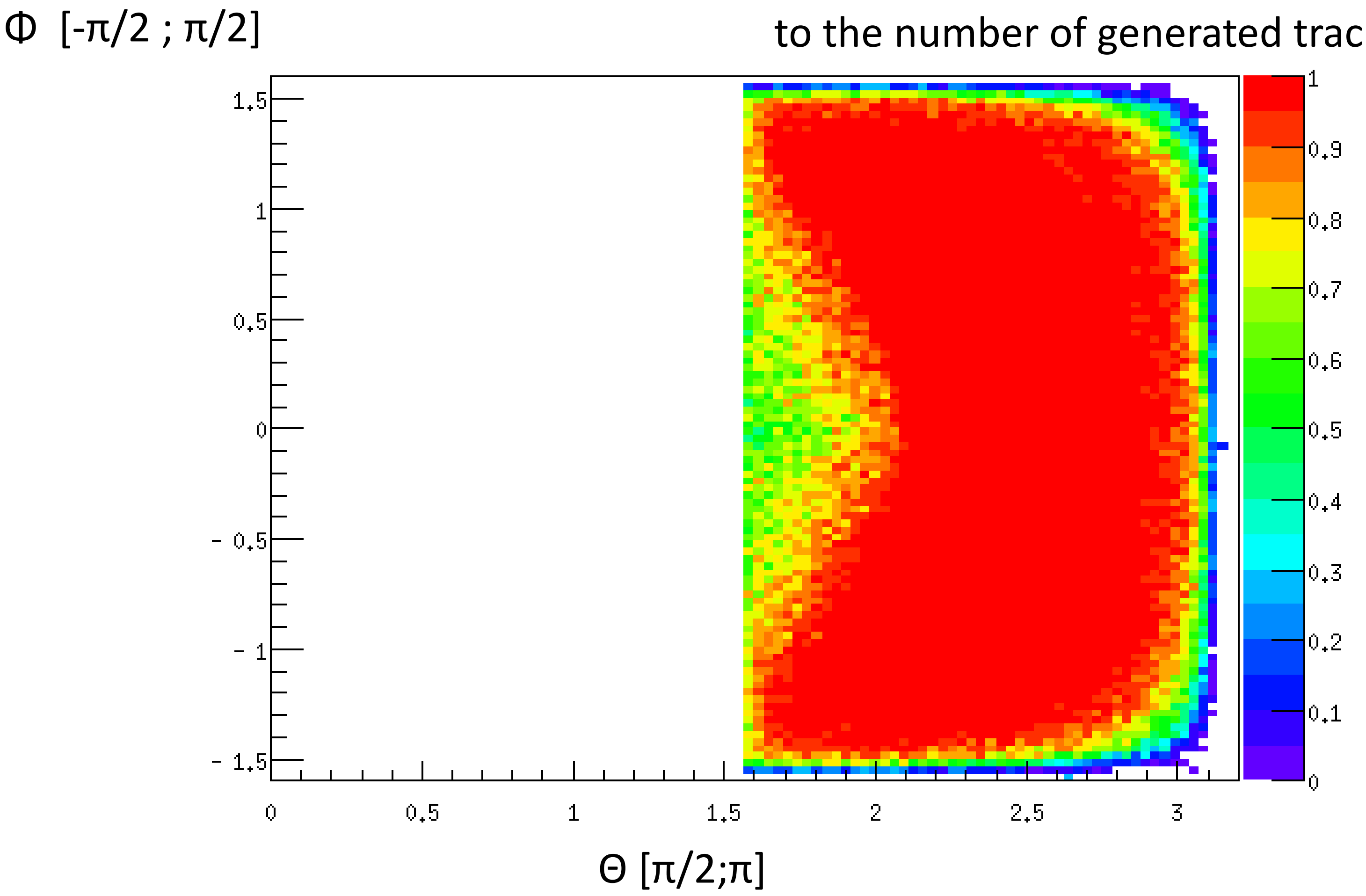


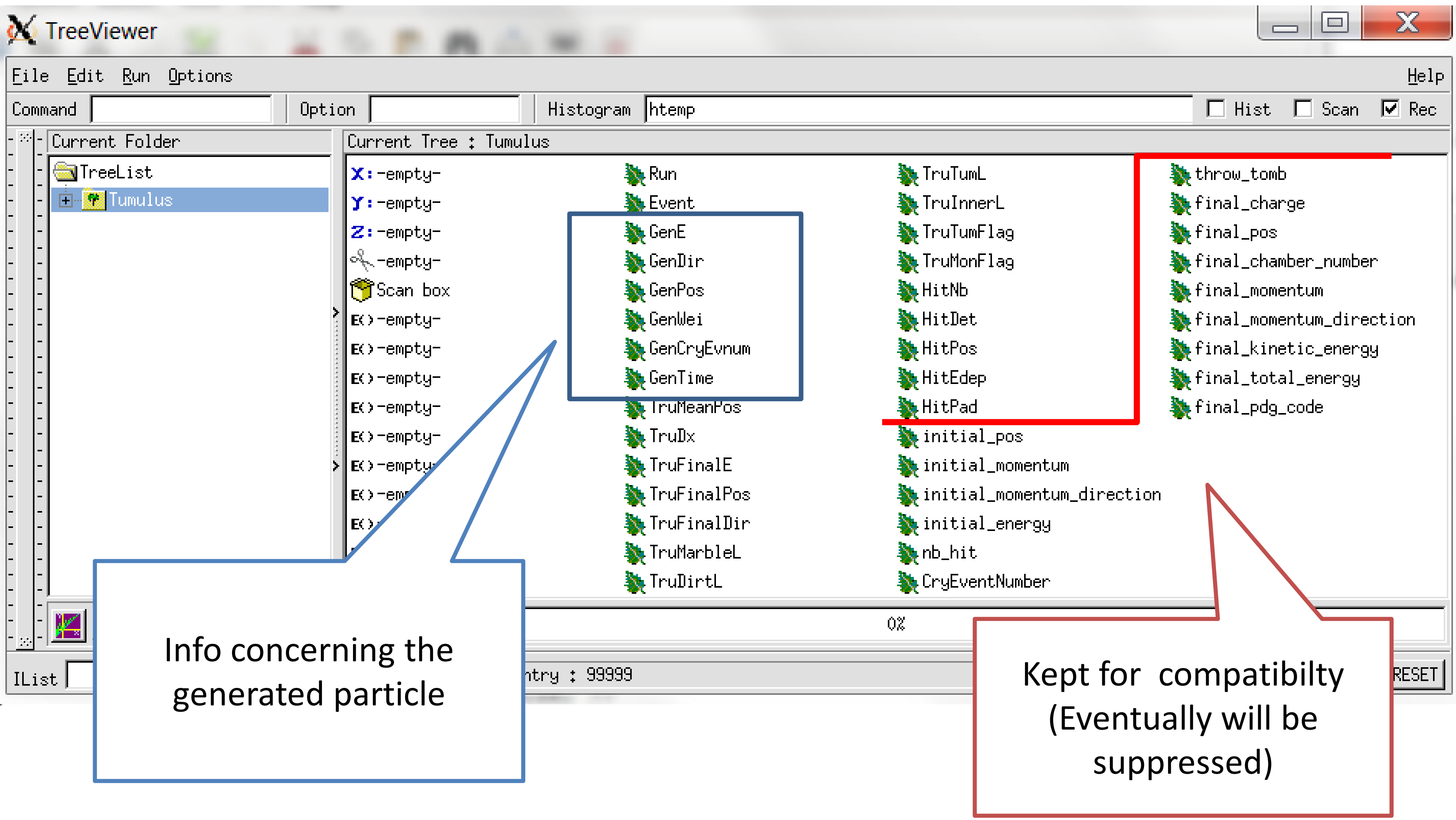


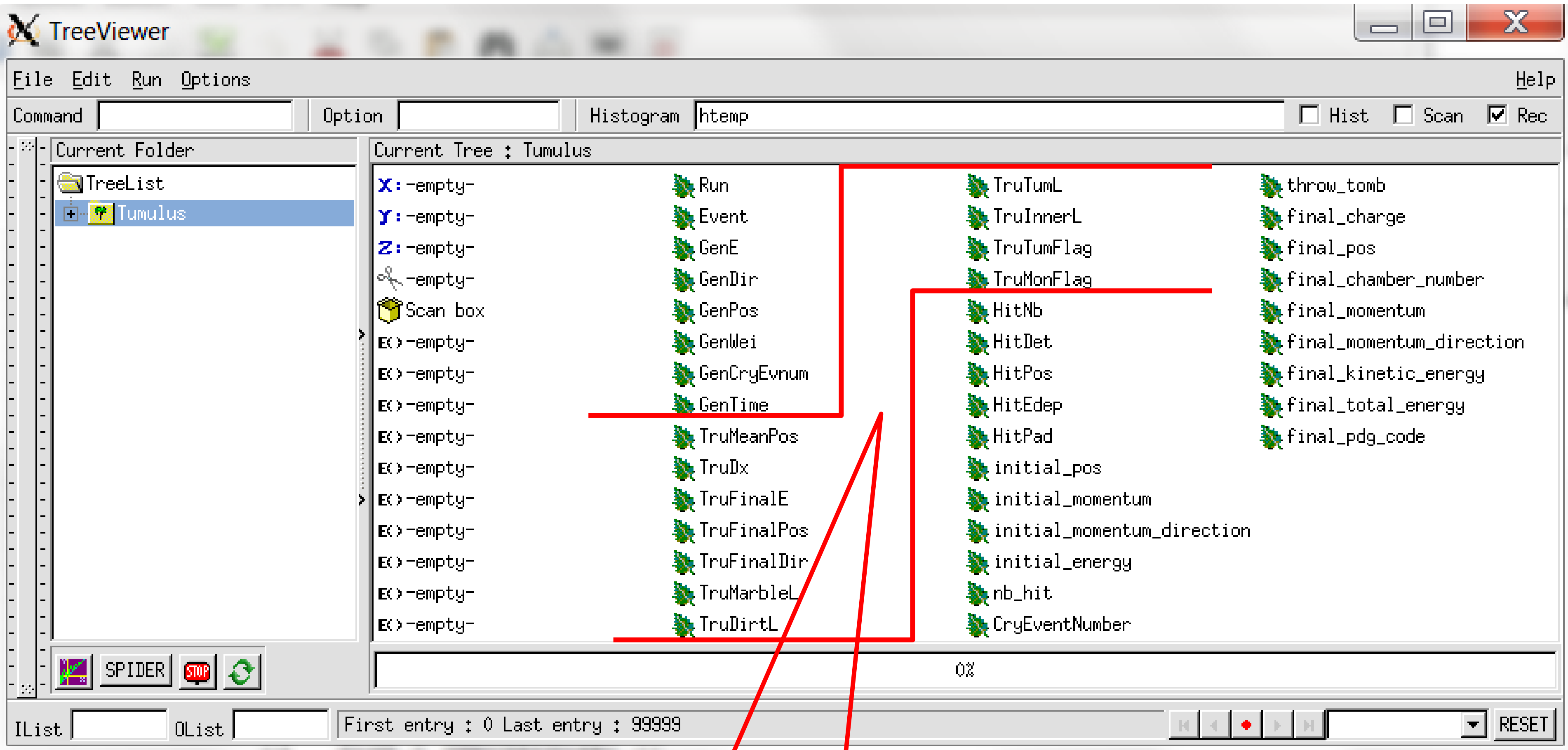
- Generate the direction randomly on the surface of the detector in limited θ and φ range.
- Range can be limited to the monument, to the tumulus etc …
- Extrapolate back on the other side of the tumulus and change direction.
- Energy is randomly taken from a (θ, E) distribution generated by CRY

Maximum range in θ and φ

Ratio of the number of tracks reaching
the detector hole
to the number of generated tracks



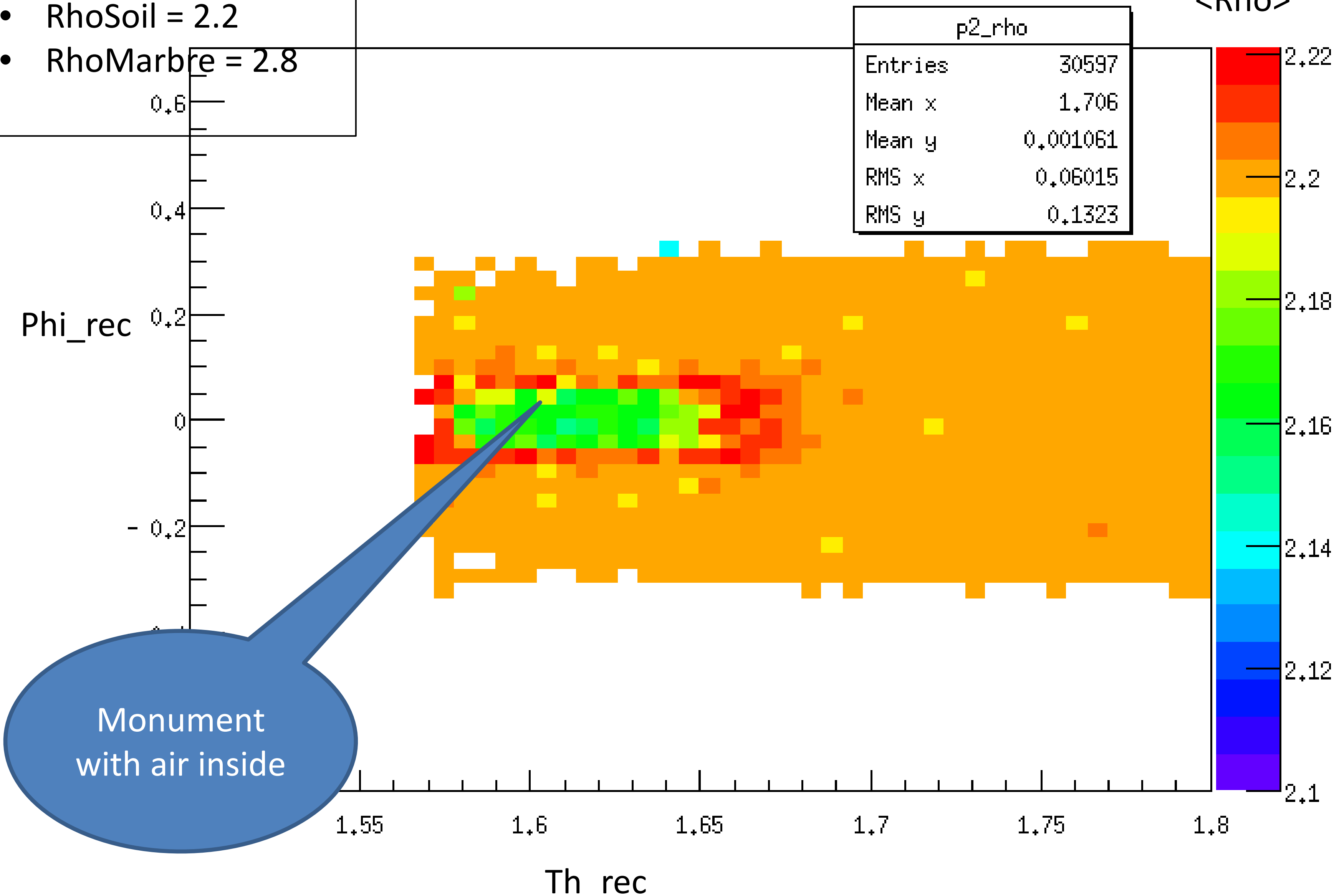

TreeViewer
File Edit Run Options Help
Command
Option
Histogram htemp
Hist Scan Rec
Current Folder
TreeList
Tumulus
Current Tree : Tumulus
X: -empty-
Y: -empty-
Z: -empty-
-empty-
Scan box
Run
Event
GenE
GenDir
GenPos
GenWei
GenCryEvnum
GenTime
TruMeanPos
TruDx
TruFinalE
TruFinalPos
TruFinalDir
TruMarbleL
TruDirtL
TruTumL
TruInnerL
TruTumFlag
TruMonFlag
HitNb
HitDet
HitPos
HitEdep
HitPad
initial_pos
initial_momentum
initial_momentum_direction
initial_energy
nb_hit
CryEventNumber
throw_tomb
final_charge
final_pos
final_chamber_number
final_momentum
final_momentum_direction
final_kinetic_energy
final_total_energy
final_pdg_code
0%
IList
RESET
Info concerning the generated particle
Kept for compatibilty (Eventually will be suppressed)

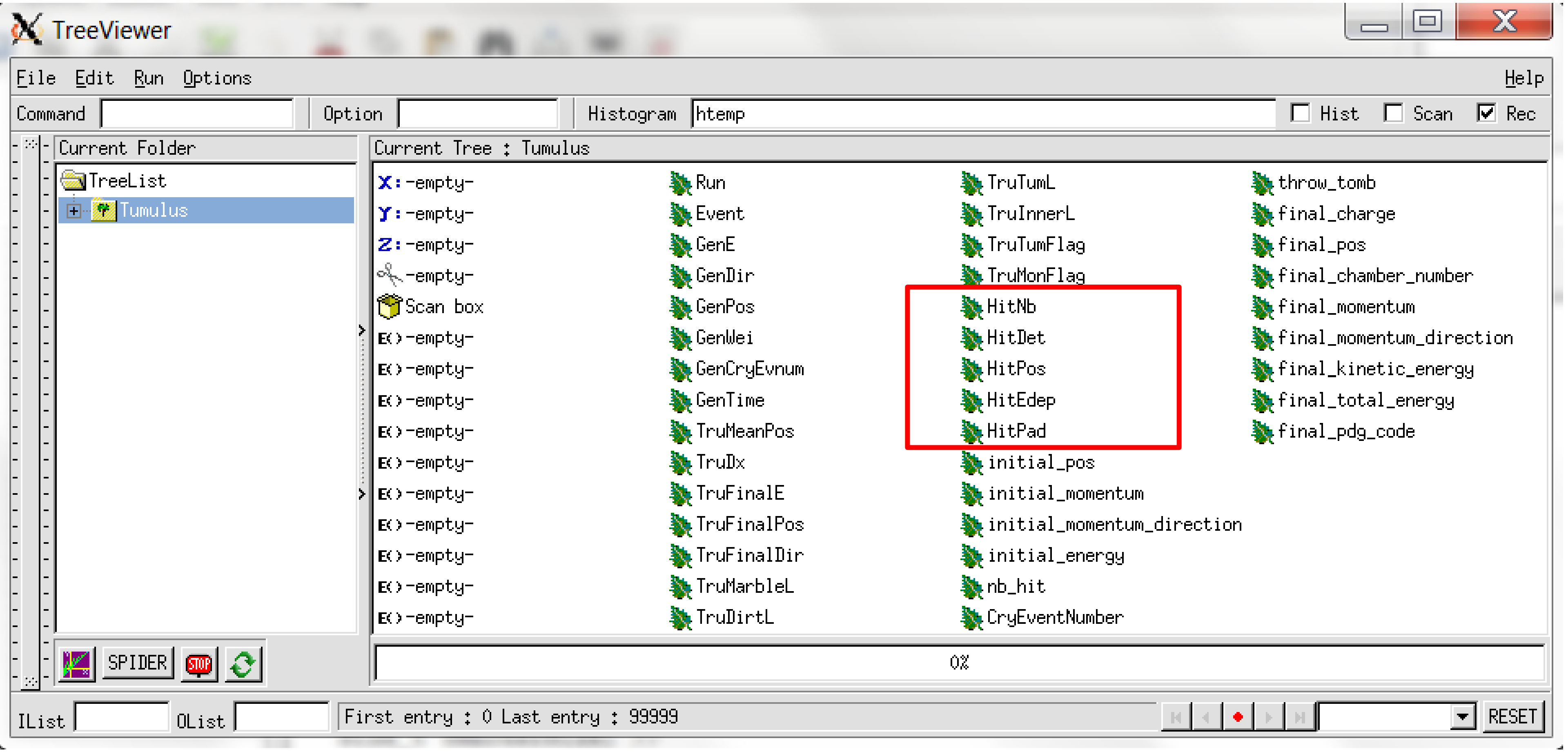


True information : in particular length traveled par the cosmic ray in different media

< rho > = Σrho*L/Ltot

- 4 detectors
- Reconstructed direction
- RhoSoil = 2.2
- RhoMarbre = 2.8





Response of the detectors

Further developments

- Several detectors

- Used the true geometry for the tumulus
    - Seems possible to interface it with Geant4

Geometrical acceptance studies

Essentially based on the paper below published in 1971

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

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

J. D. SULLIVAN†

Enrico Fermi Institute and Dept. of Physics, The University of Chicago, Chicago, Illinois 60637, U.S.A.

Counting rate through a surface

$$C(\boldsymbol{x}, t_0) = (1/T) \int_{t_0}^{t_0+T} \mathrm{d}t \int_S \mathrm{d}\boldsymbol{\sigma} \cdot \hat{\boldsymbol{r}} \int_\Omega \mathrm{d}\omega \int_0^\infty \mathrm{d}E \times$$

$$\times \sum_\alpha \varepsilon_\alpha(E, \boldsymbol{\sigma}, \omega, t) J_\alpha(E, \omega, \boldsymbol{x}, t), \quad (1)$$

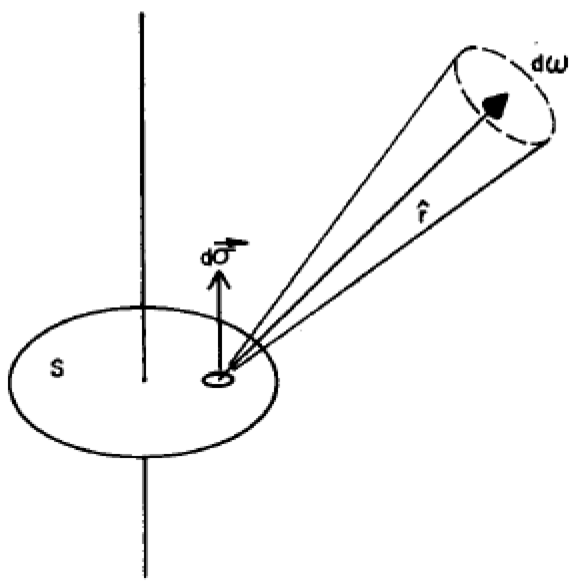


Fig. 1. A telescope with a single plane detector viewing one hemisphere.

Main simplification :

- E dependence can be decoupled from θ
- Flux Isotropic in Phi

>> J(E,ω,x,t) = J0 (E)*F(θ)

- Detector efficiency == 1

(and does not depend on E , time position , particle type)

$$C(\mathbf{x}, t_0) = (1/T) \int_{t_0}^{t_0 + T} \mathrm{d}t \int_S \mathrm{d}\boldsymbol{\sigma} \cdot \hat{\boldsymbol{r}} \int_\Omega \mathrm{d}\omega \int_0^\infty \mathrm{d}E \times$$

$$\times \sum_\alpha \varepsilon_\alpha(E, \boldsymbol{\sigma}, \omega, t) J_\alpha(E, \omega, \mathbf{x}, t) , \quad (1)$$

$$C = I \int_S \mathrm{d}\vec{\sigma} \cdot \vec{r} \int_\Omega \mathrm{d}\omega \; F(\theta)$$

This Geometrical factor cannot be calculated independently of the shape of the flux F

Examples : Geometrical factor of an horizontal surface

$F(\theta) = 1$;Isotropic

Typically cosmic rays in space.

$$G = \int_S d\sigma \cdot \iint_{\theta\,\varphi} 1 \cdot \sin\theta \, d\theta \, d\varphi \, \underbrace{\vec{dr} \cdot \vec{n}}_{-\cos(\theta)}$$

$$= S \left[\varphi \right]_0^{2\pi} \left[+ \frac{1}{2} \cos^2 \theta \right]_{\pi/2}^{\pi}$$

$$= \pi S$$

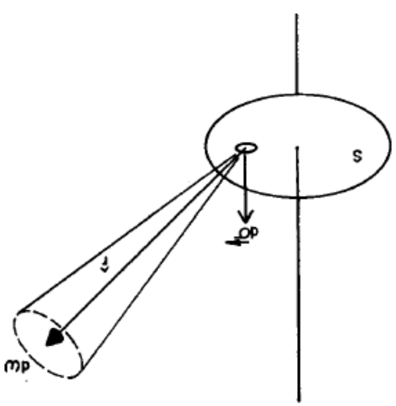
$F(\theta) = \cos^2(\theta)$

Cosmic muons on earth

$$G = S \iint \cos^2\theta \sin\theta \cos\theta \, d\theta \, d\varphi$$

$$= S \left[\varphi \right]_0^{2\pi} \left[+ \frac{1}{4} \cos^4 \theta \right]_{\frac{\pi}{2}}^{\pi}$$

$$= \frac{\pi S}{2}$$



We don't have just a surface but a detector!

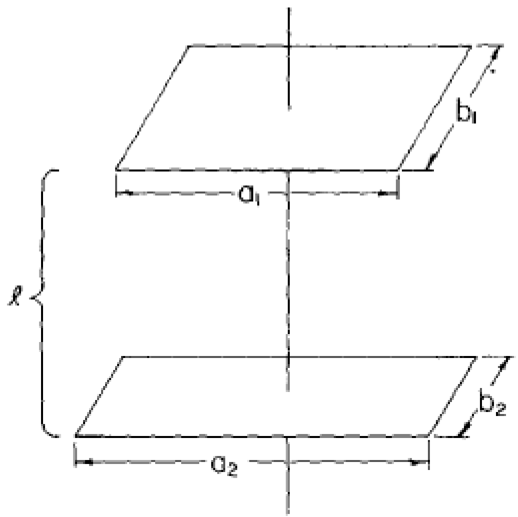


Fig. 3. An ideal cylindrically symmetric telescope with two rectangular detectors.

Calculated in the case of Isotropic flux shape !

2. *Rectangular symmetry:* For a telescope wit rectangular detectors with sides (a_1, b_1) and $(a$ and where a_1 and b_1 are parallel to a_2 and b_2 re tively (cf. fig. 3), the geometrical factor is still obt by integrating eq. (5). Whence

$$G = l^2 \ln \frac{l^2+\alpha^2+\delta^2}{l^2+\alpha^2+\beta^2} \, \frac{l^2+\gamma^2+\beta^2}{l^2+\gamma^2+\delta^2} +$$

$$+ 2\alpha(l^2+\beta^2)^{\frac{1}{2}} \tan^{-1} \frac{\alpha}{(l^2+\alpha^2)^{\frac{1}{2}}} +$$

$$+ 2\beta(l^2+\alpha^2)^{\frac{1}{2}} \tan^{-1} \frac{\beta}{(l^2+\beta^2)^{\frac{1}{2}}} -$$

$$- 2\alpha(l^2+\delta^2)^{\frac{1}{2}} \tan^{-1} \frac{\alpha}{(l^2+\delta^2)^{\frac{1}{2}}} -$$

$$- 2\beta(l^2+\gamma^2)^{\frac{1}{2}} \tan^{-1} \frac{\beta}{(l^2+\gamma^2)^{\frac{1}{2}}} -$$

$$- 2\gamma(l^2+\beta^2)^{\frac{1}{2}} \tan^{-1} \frac{\gamma}{(l^2+\beta^2)^{\frac{1}{2}}} -$$

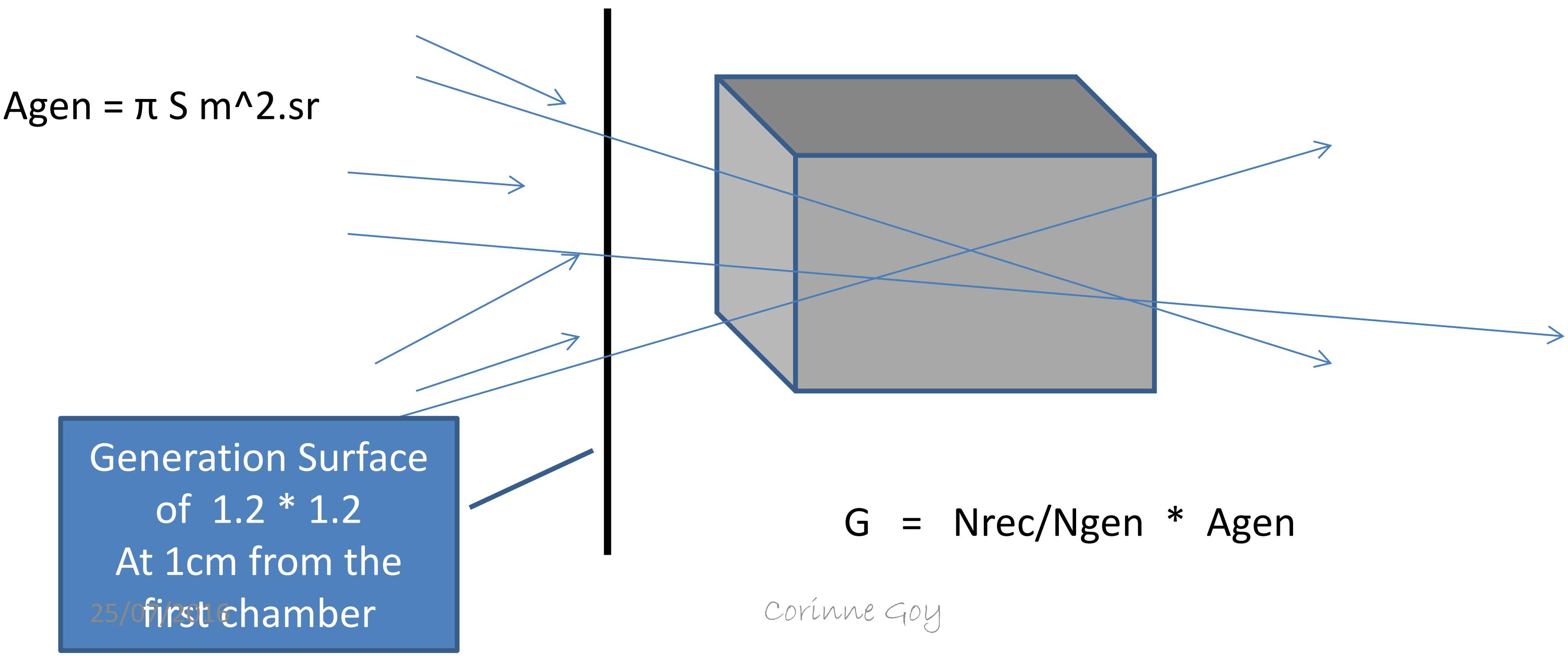
$$- 2\delta(l^2+\alpha^2)^{\frac{1}{2}} \tan^{-1} \frac{\delta}{(l^2+\alpha^2)^{\frac{1}{2}}} +$$

$$+ 2\gamma(l^2+\delta^2)^{\frac{1}{2}} \tan^{-1} \frac{\gamma}{(l^2+\delta^2)^{\frac{1}{2}}} +$$

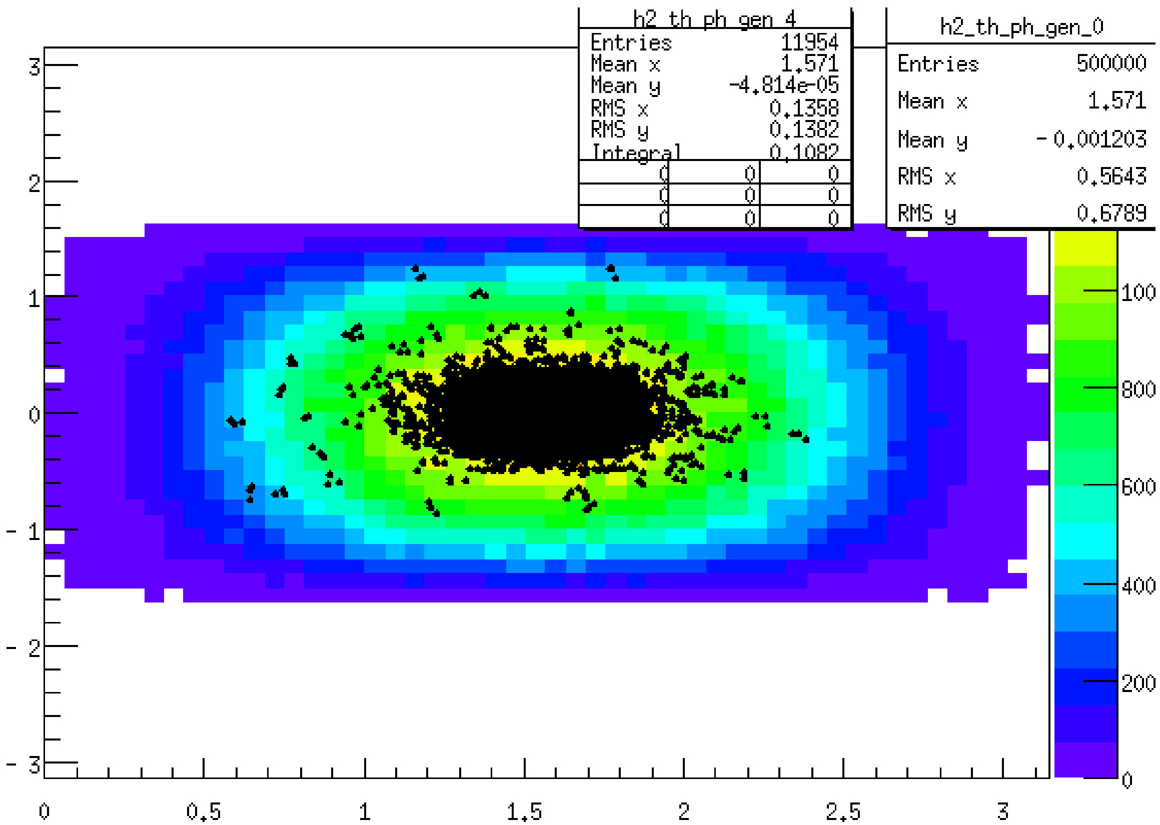
$$+ 2\delta(l^2+\gamma^2)^{\frac{1}{2}} \tan^{-1} \frac{\delta}{(l^2+\gamma^2)^{\frac{1}{2}}},$$

Cross-checks (1)

- Use our simulation (forget about tumulus)
  - Last option of PrimaryGeneratorAction
- Generate Isotropic particles (F(θ) = 1) on a vertical surface S .



G = 0.108 m^2.sr



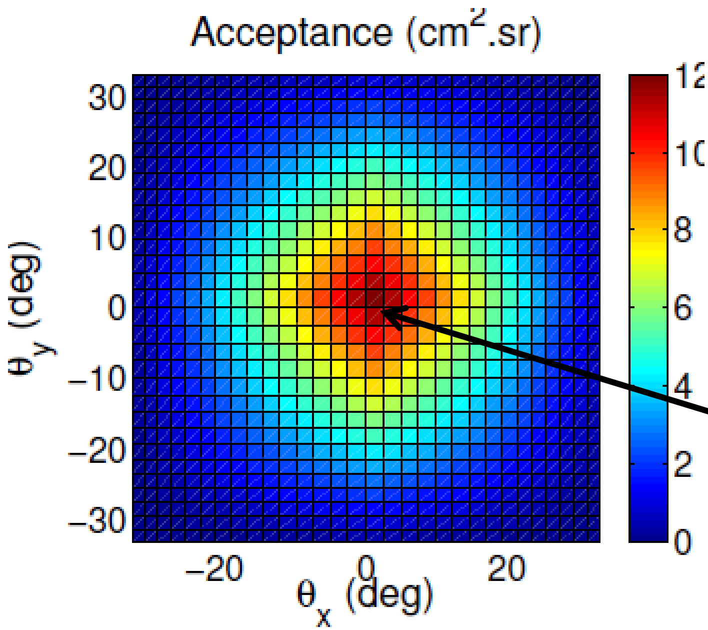
- Sullivan formula with
  - a = 1m
  - l = 3 m

G = 0.103 m^2.sr

Some cross-checks (2)

Design and operation of a field telescope for cosmic ray geophysical tomography

N. Lesparre[1,*], J. Marteau[2], Y. Déclais[2], D. Gibert[1], B. Carlus[2], F. Nicollin[3], and B. Kergosien[3]



Sullivan's formula with the pad dimensions

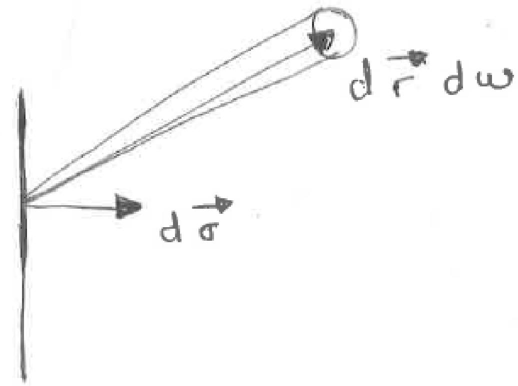
A = 5cm

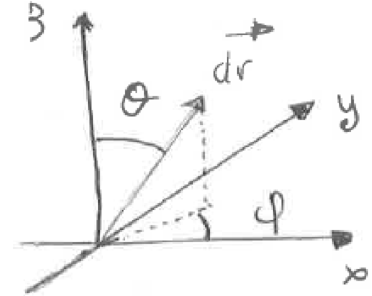
L = 115 cm

G = 0.047 cm^2.sr

G*16*16 = 12.03 cm^2.sr

Useful case:
$F(\theta) = \cos^2(\theta)$
Generation on a vertical plane





$$\vec{d\sigma} = d\sigma\, \vec{x}$$

$$\vec{dr} \begin{cases} \sin\theta \cos\varphi \\ \sin\theta \sin\varphi \\ \cos\theta \end{cases}$$

$$G = F(\theta)\, d\vec{\sigma} \cdot d\vec{r}\, d\omega$$

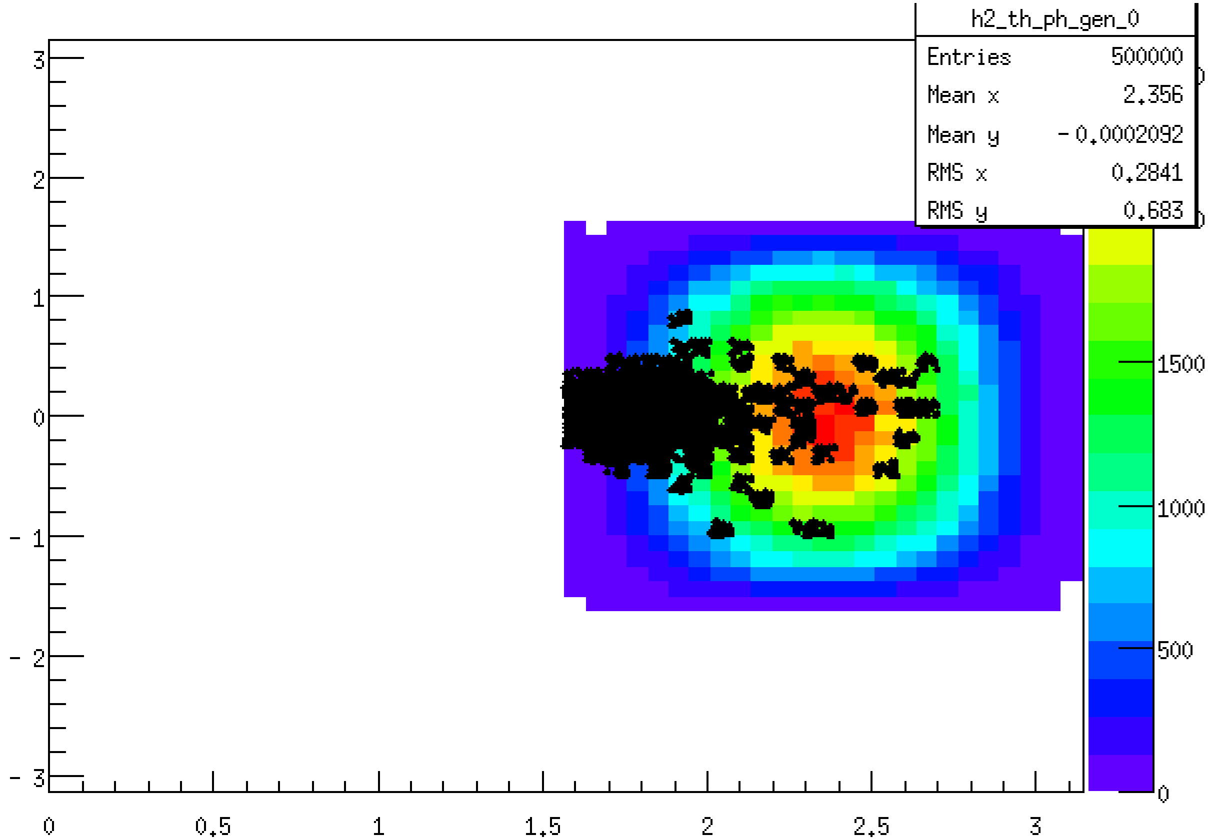
$$= \cos^2\theta\, d\sigma \sin\theta \cos\varphi \sin\theta\, d\theta\, d\varphi$$

$$= d\sigma\, (\cos^2\theta \sin^2\theta\, d\theta)(\cos\varphi\, d\varphi)$$

$$= S \left[\frac{4\theta - \sin 4\theta}{32} \right]_{\frac{\pi}{2}}^{\pi} \left[\sin\varphi \right]_{-\frac{\pi}{2}}^{\frac{\pi}{2}}$$

$$= S \frac{\pi}{16} \times 2$$

$$= S \frac{\pi}{8}$$



$$G = Nrec/Ngen * Agen\ (= \pi\ S/8\ m^2.sr)$$

$G = 0.00096\ m^2.sr$

Number of muons per hour from CRY in the acceptance

- Flux = 92 muons/m2.s
  - 317 muons/ hour (Efficiency = 1)
- > 1 GeV : Flux = 73 muons/m2.s
  - 252 muons / hour
- **> 60 GeV : Flux = 0.7 muons/m2.s**
  - **2.7 muons / hour in the acceptance of the detector**

Check that CRY flux is generated as $\cos^2(\theta)$

- Generation on horizontal plane so :

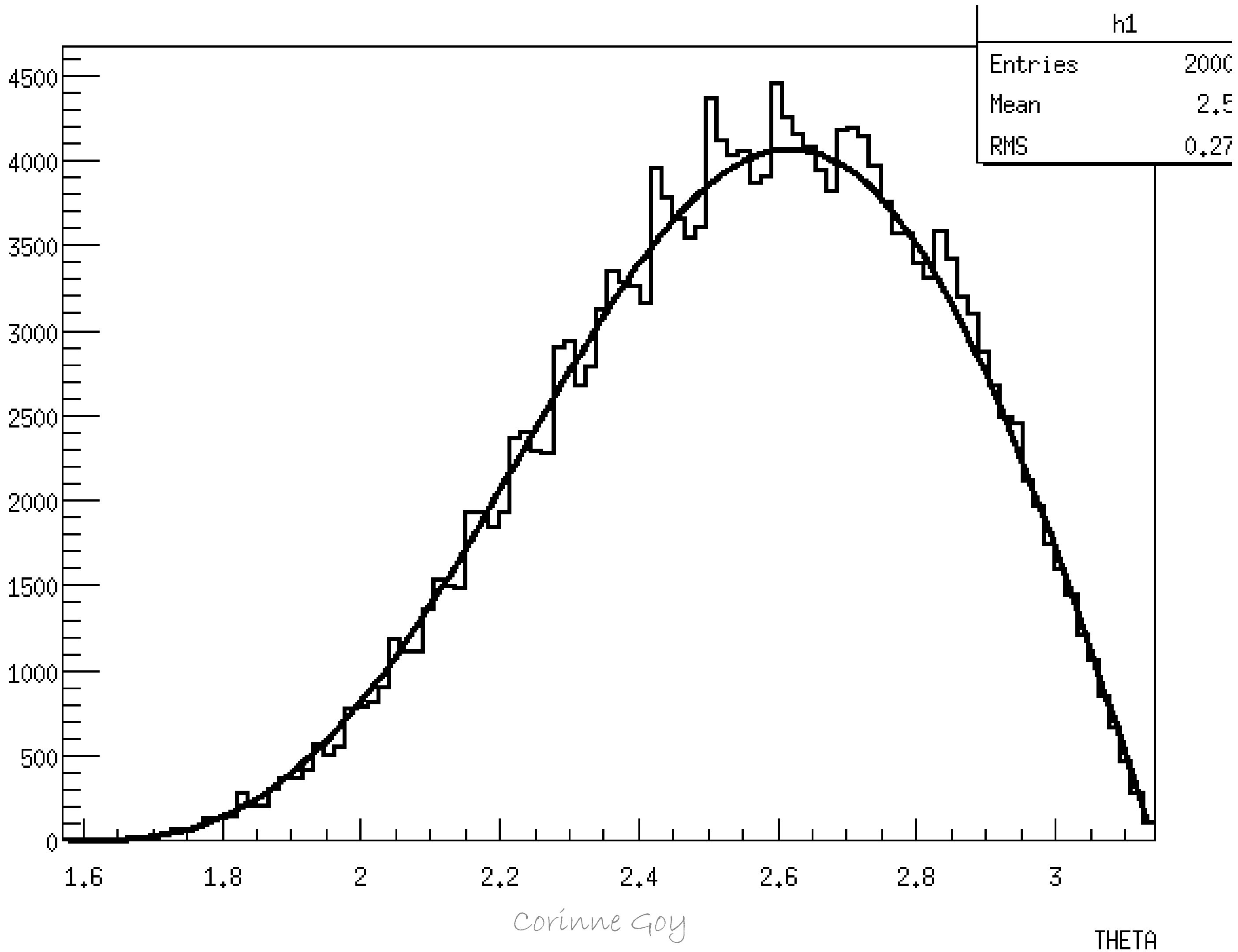
$$\Phi = S \iint \cos^2\theta \sin\theta \cos\theta \, d\theta \, d\varphi$$

$$= S \left[\varphi\right]_0^{2\pi} \left[+\frac{1}{4}\cos^4\theta\right]_{\frac{\pi}{2}}^{\pi}$$

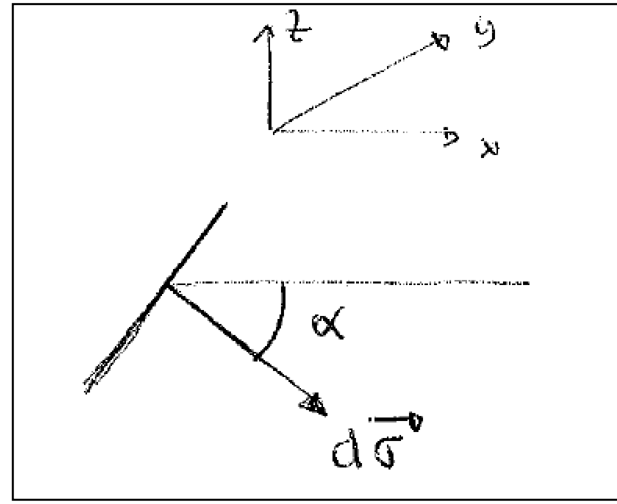
$$= \frac{\pi S}{2}$$

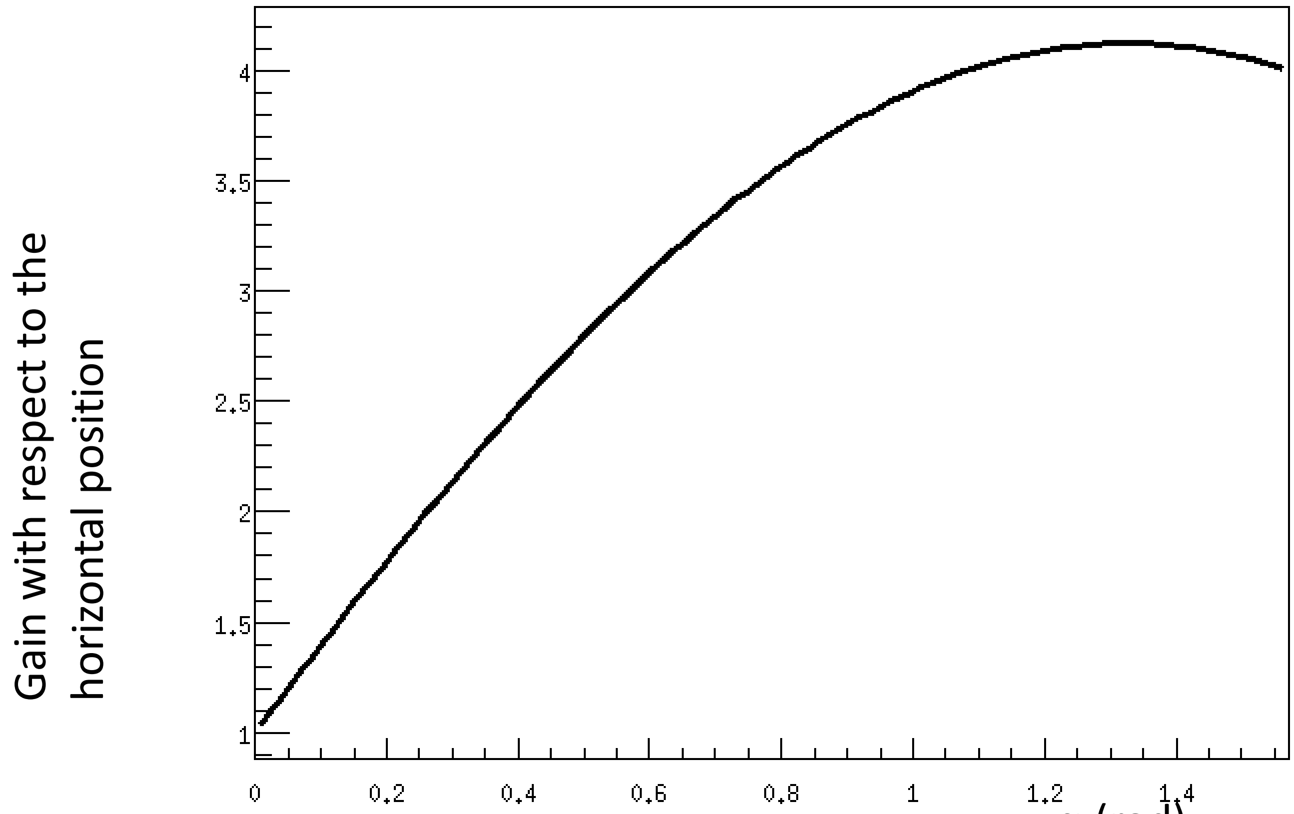
The differential theta distribution must follow the function of theta in red

Theta distribution of the CRY particle



Inclined detector (to be checked)



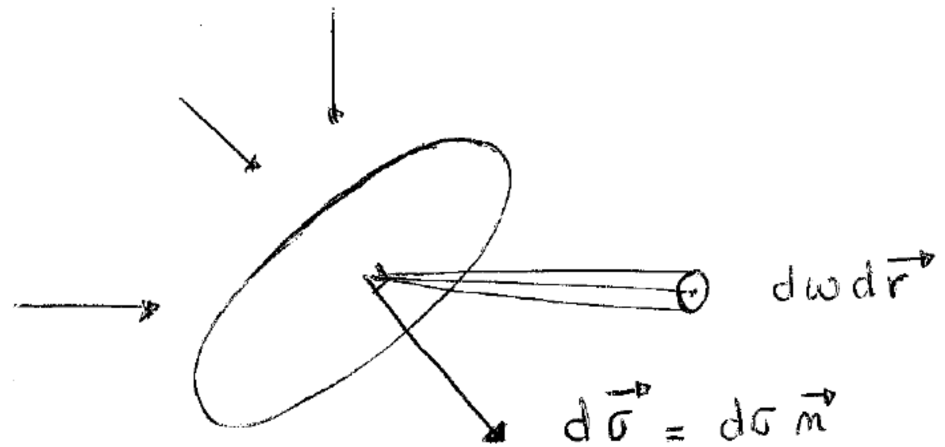


Conclusion

- The simulation program was consolidated:
  - Improve the “digitization” step with customable granularity.
  - Interface with other cosmic generators
  - Interface with “real” geometry

- The geometrical acceptance is understood and computable.
  - Optimization of inclination, length of the detector depending of the position …

Geometrical factor of a surface



$$d\phi = F(\theta)\, d\omega\, d\vec{r} \cdot d\vec{\sigma}$$
$$= F(\theta) \sin\theta\, d\theta\, d\varphi\, d\vec{r}\, d\vec{\sigma}$$
$$= d\sigma \iint_{\theta\, \varphi} F(\theta) \sin\theta\, d\theta\, d\vec{r} \cdot \vec{n}$$

This cannot be calculated independently of the shape of the flux

$F(\theta) = 1$
Isotropic flux - typically cosmic rays in space

$F(\theta) = \cos^2(\theta)$
Cosmic muon on earth

PrimaryGeneratorAction

```
// Option 4 - generation according to cos^2 for acceptance only
fGenCos2th = new TF1("fGenCos2th","cos(x)*cos(x)*sin(x)*sin(x)",acos(-1.)/2.,acos(-1.));
fGenCos2ph = new TF1("fGenCos2ph","cos(x)",-acos(-1)/2.,acos(-1.)/2);
```

```
 G4double th = fGenCos2th->GetRandom(acos(-1.)/2.,acos(-1.))
 G4double ph = fGenCos2ph->GetRandom();
```

```
 dir[0] = sin(th)*cos(ph);
 dir[1] = sin(th)*sin(ph);
 dir[2] = cos(th);
```