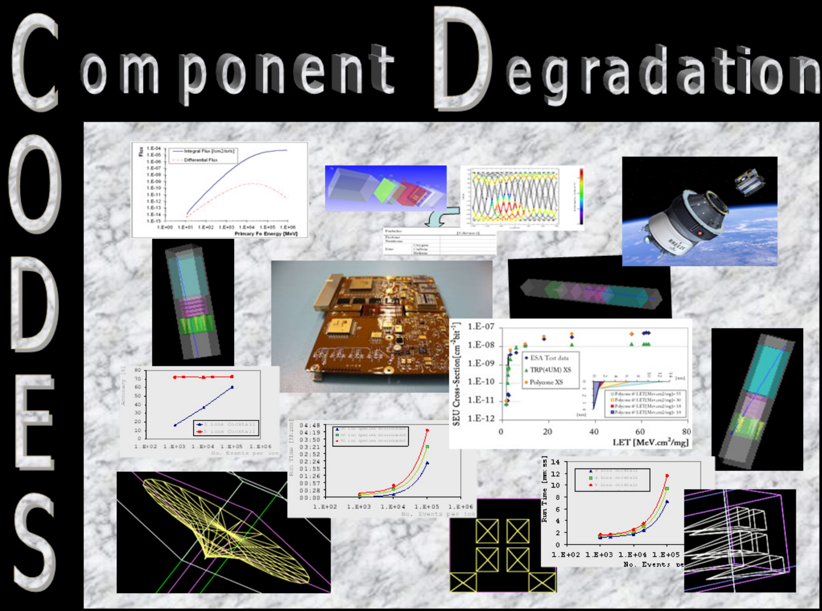
Simulation of Single Event Effects and rate prediction. CODES an ESA tool

component degradation simulation tool



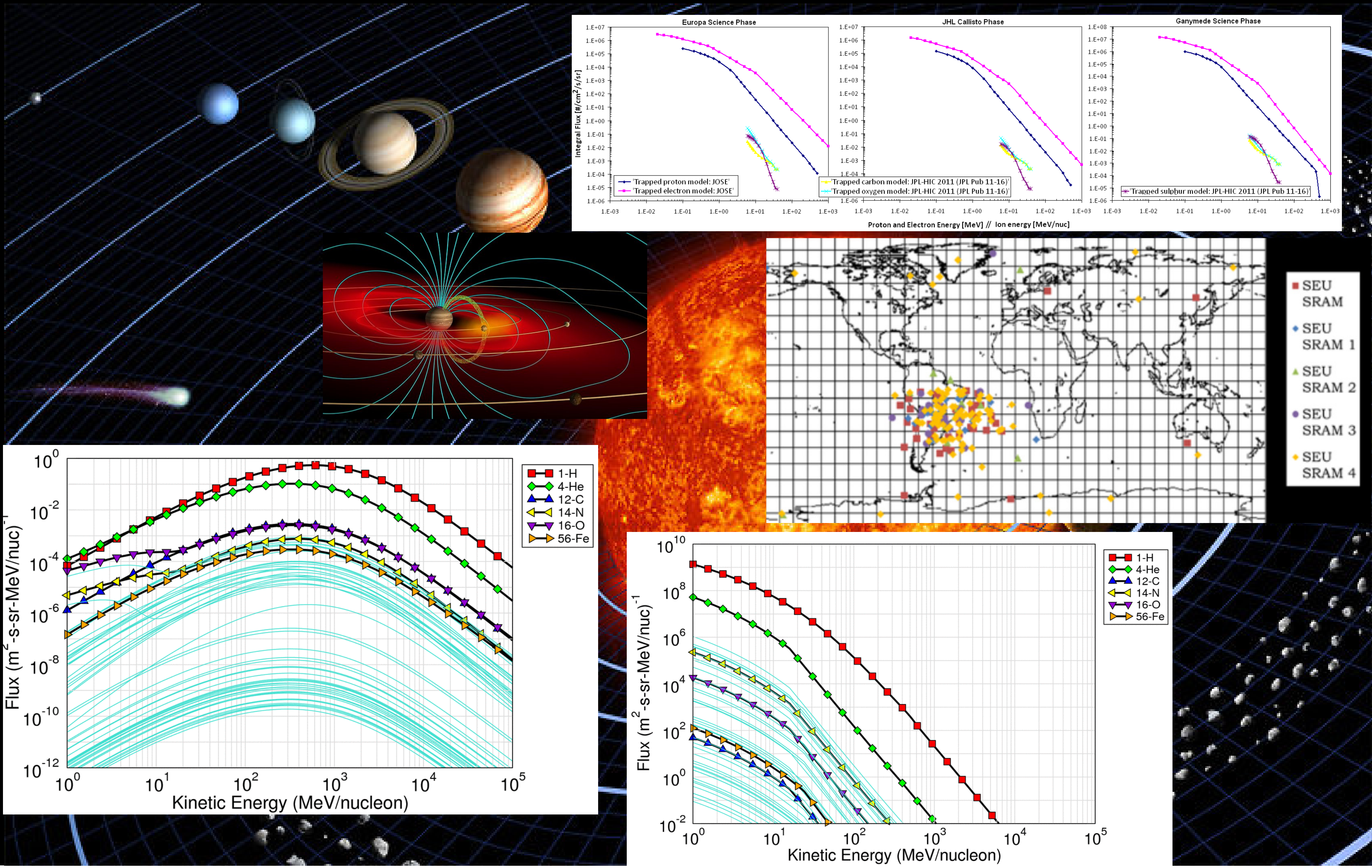
A. Keating, S. Joyce, A. Zadeh, M. Pimenta, E.Daly, P.Gonçalves

ESA Project:
18121/04/NL/CH

Outline

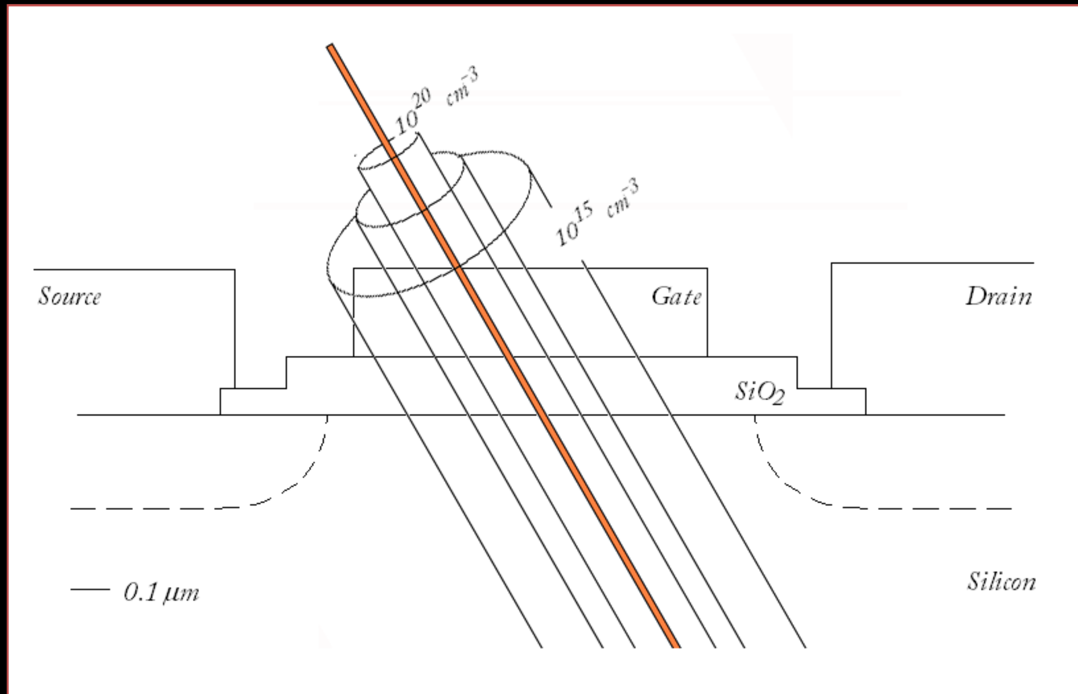
- Simulation of SEE effects
  - Environment thru shielding and processing layers
  - Energy deposition distribution at SV
- Sensitive Volume Fit (SVFIT) Module
- CODES: the top level integrated tool
- Additional Models developed to be included later
- Conclusions

Radiation Environment



Single Event Effects

- A transient phenomenon : Decaying with time
- *e-h pair generation threshold* in the target material (3.6eV Si)

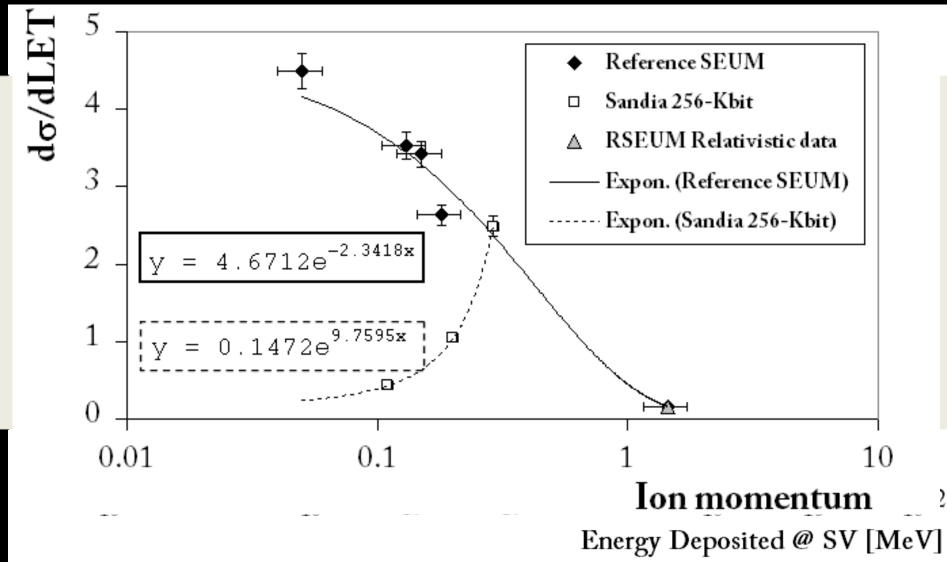


SEE Mechanisms: Stopping power and nuclear Reactions

- Keating et al. (2012). Modelling the effects of low-LET cosmic rays on electronic components, Radiat Environ Biophys, **DOI 10.1007/s00411-012-0412-2**.

$$\sigma_{\mathrm{SEU}} \propto \left(\left[\int_{x=0}^{x=l} \frac{\mathrm{d}E^a}{\mathrm{d}x}\, \mathrm{d}x \right] \cdot \sigma[X(a,b)Y] \cdot \eta_c(x) \cdot f[Z,A]^{\mathrm{target}} \right)$$

- Stopping power
- σ[X(a, b)y] nuclear cross section
- $\eta_c(x)$ is the charge collection yield
- Z and A



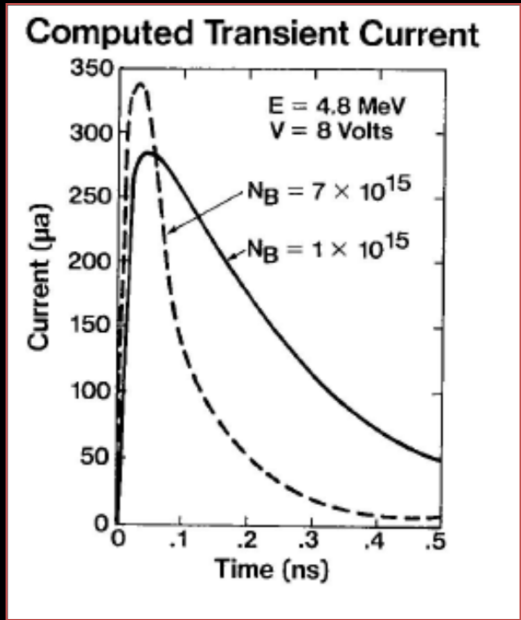
Drift & Diffusion in the semiconductor

- Electron-hole pairs are separated and transported by the electric field (drift) and by diffusion

$$J_i = \underbrace{q\, n_i\, \mu_i\, E}_{\text{drift}} + \underbrace{q\, D_i\, \mathrm{grad}(n_i)}_{\text{diffusion}}; \qquad i=e,h$$

- Drift: t~0.5ns d<10µm
- Diffusion: t>0.5ns d>10µm

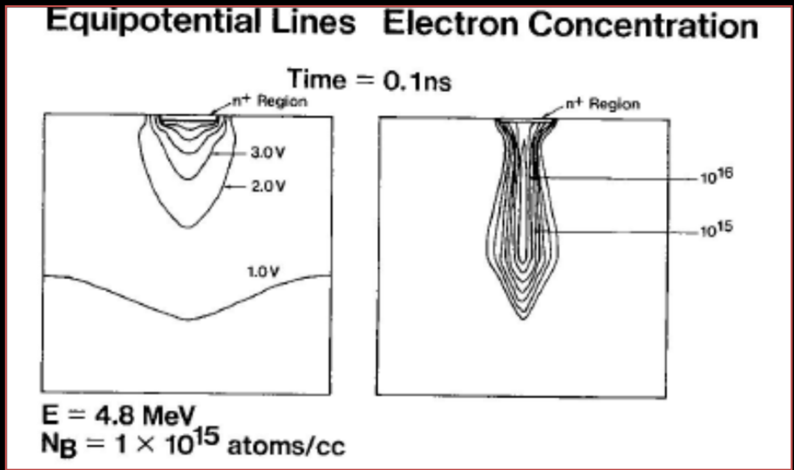
- Part may recombine
(function of injection level, Ma 1989)
- Charges collected by electrodes may propagate thru the circuit: *Transient "ionocurrent"*

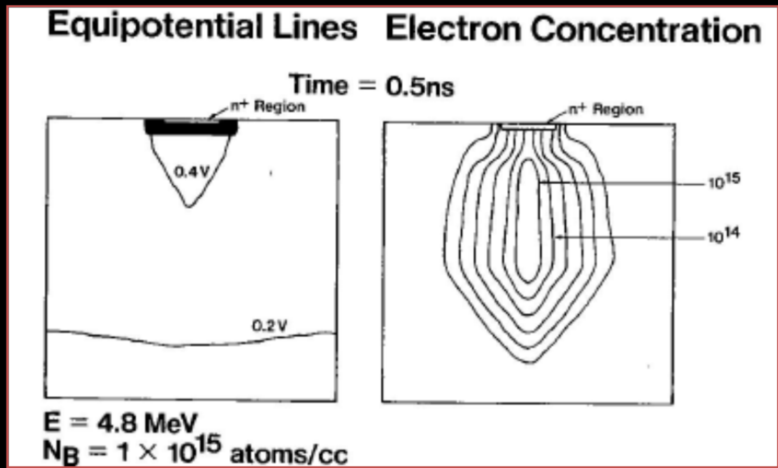


Drift & Funnelling

C. M. Hsieh, P. C. Murley, 1981

- Drift charge : prompt charge collection (~0.5ns)
- Before the ion the *Electrical field, E,* is limited to the *depletion region*
- The ion track (or the e-h pair plasma) extends E far down into bulk Si

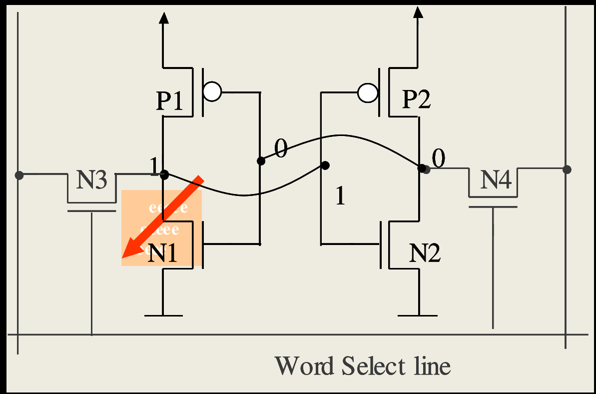


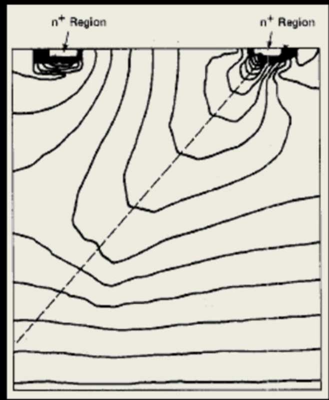


Device Response

- The device behaviour depends on the field (ξ), Incoming particle (βγ ~P/M) and on the angle of incidence (θ)

$$Q_{collected} = f(\xi, \lambda, \theta) > Q_{crit}$$



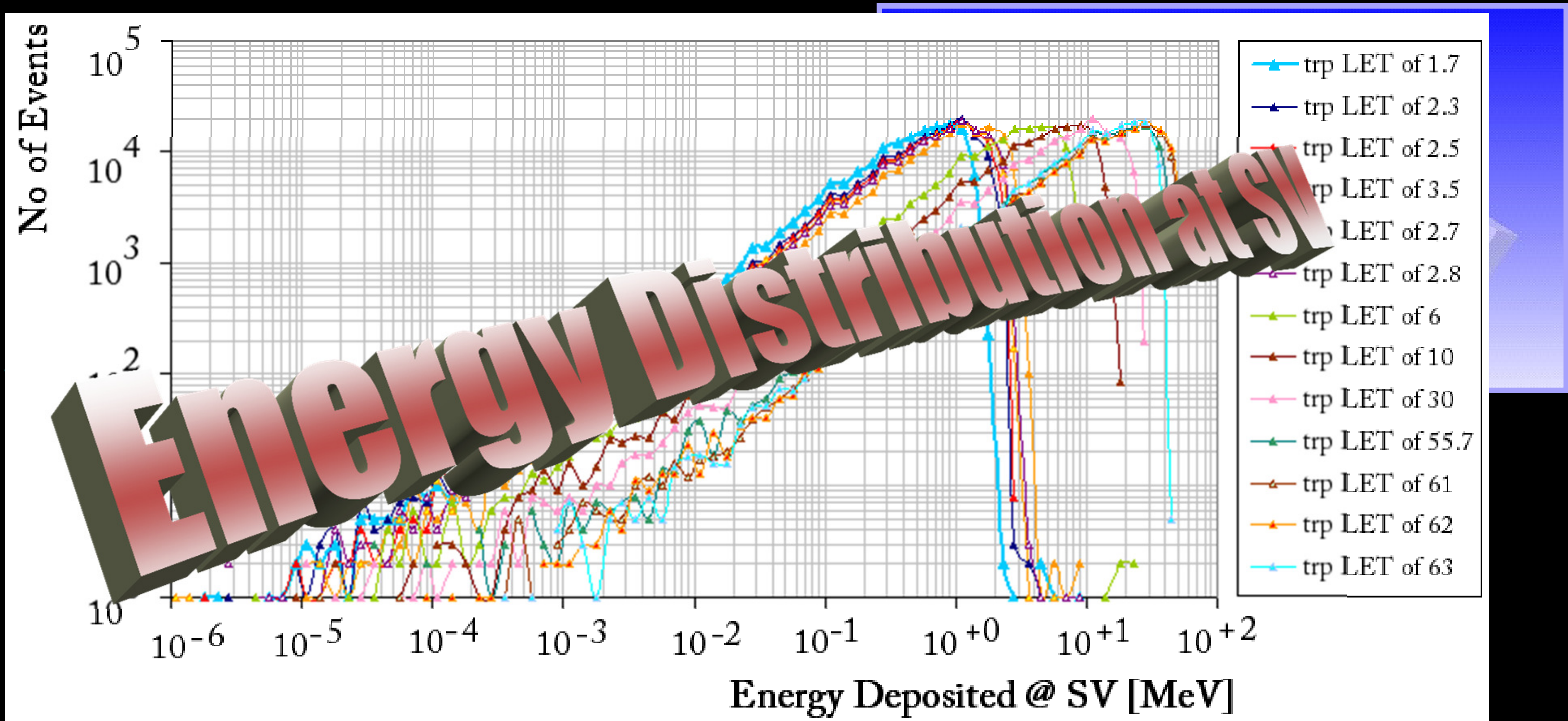


- The critical charge depends on the node capacitance, voltage and the response time of the device

$$Q_{crit} = C_{node} \cdot V_{node} + \tau_{switch} \cdot I_{restore}$$

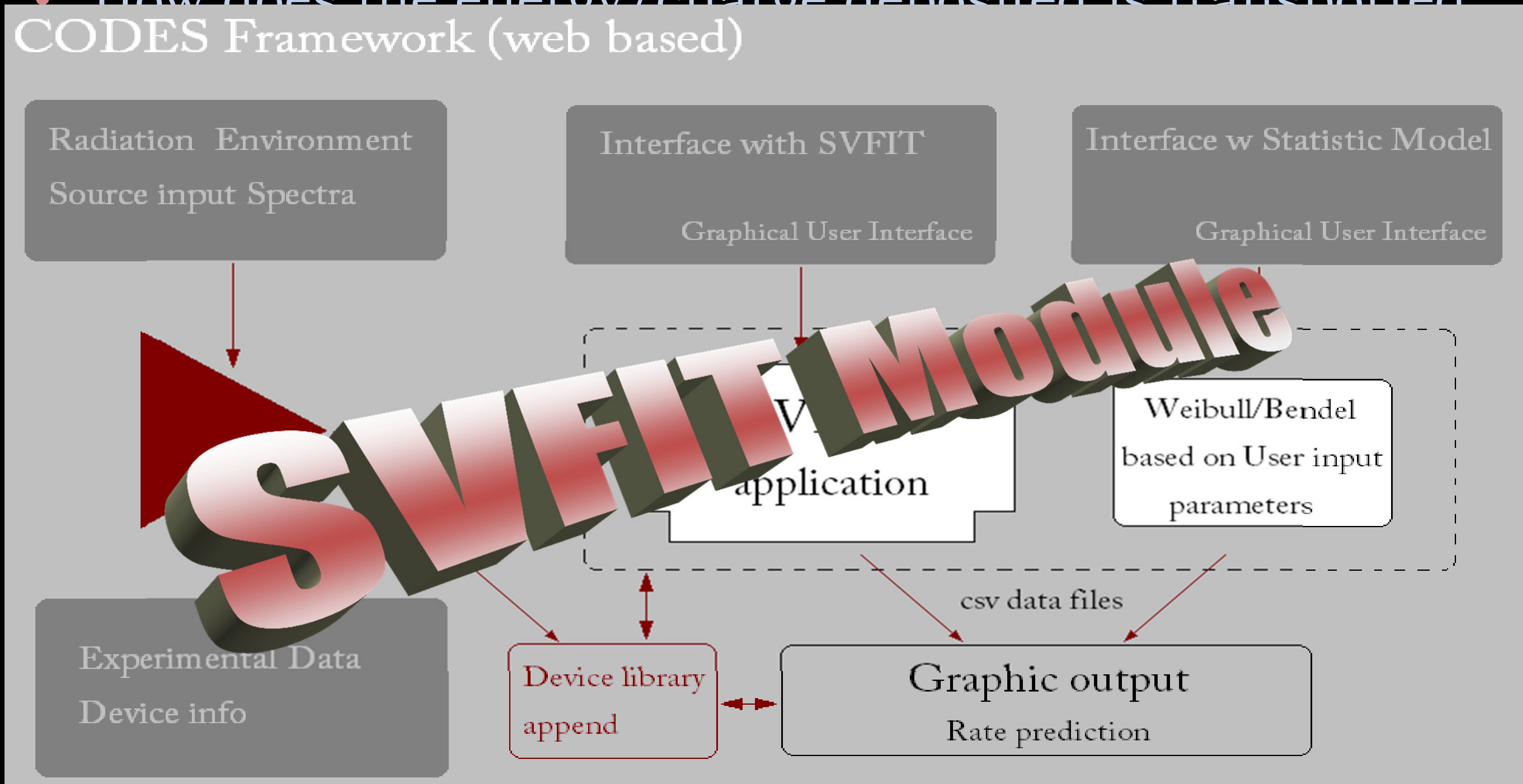
Which answers can GEANT4 Give?

- Particle physics simulation tool, for particle transport and interaction with matter used for simulating:



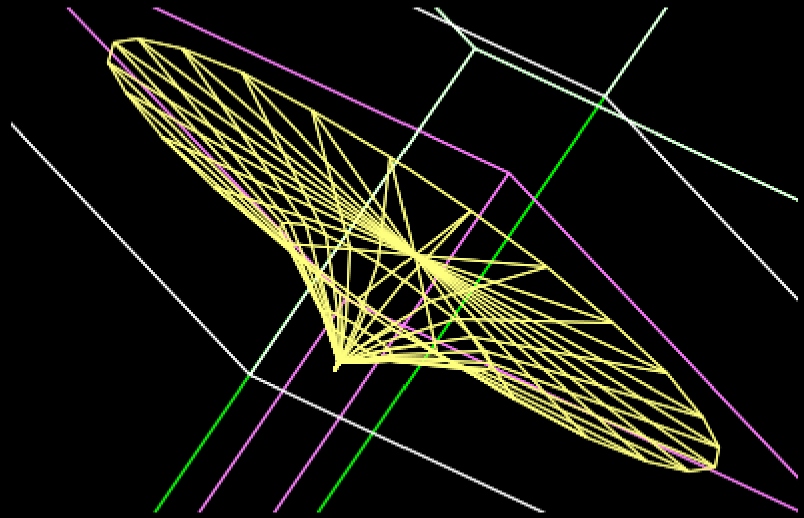
What are the remaining questions?

- How does the energy/charge deposited is transported



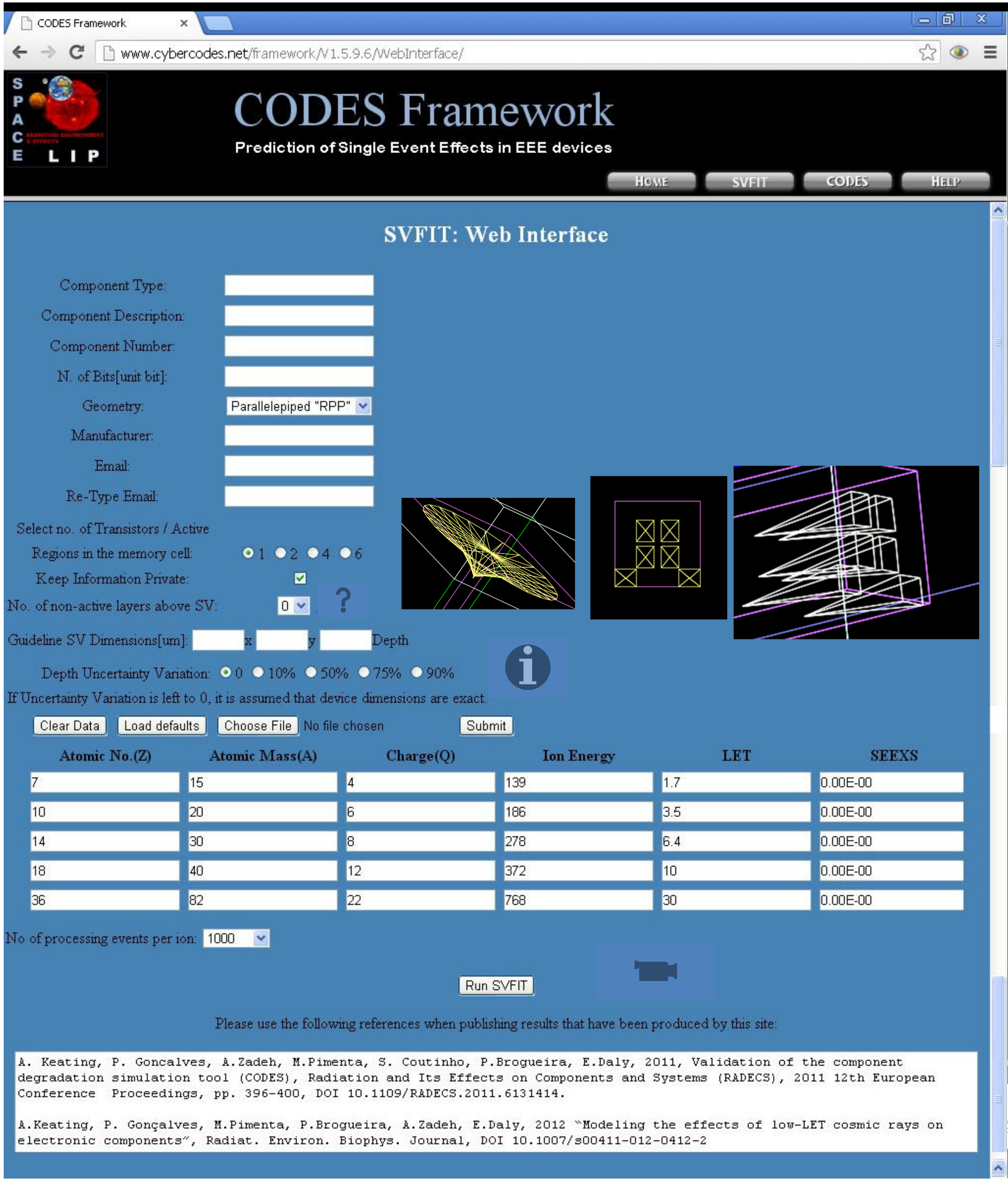
How ?

- Experimental data
  - Device Response function
  - Function of field effects
  - Cristal lattice effects
  - Experimental conditions



- SVFIT:
  - Fits device sensitivity to adjust experimental device response function

SVFIT: Web interface



- SVFIT_V. 1.5.7
- Meta Information
- SV geometry
- Email account
- Efficiency matrix: No of SV

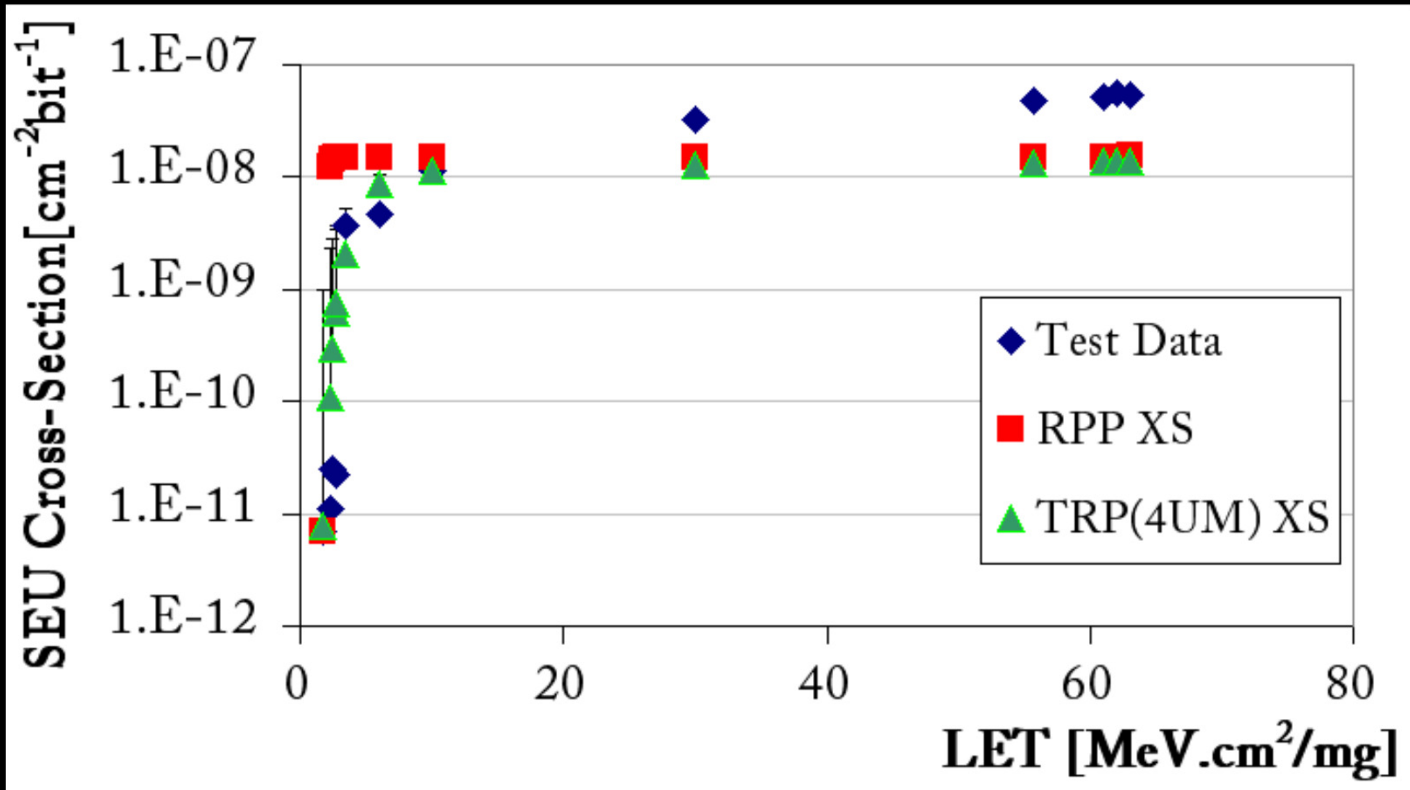
- Library
- Non Active layers

- Guideline SV dimensions
- Depth uncertainty -> Interactive Fit

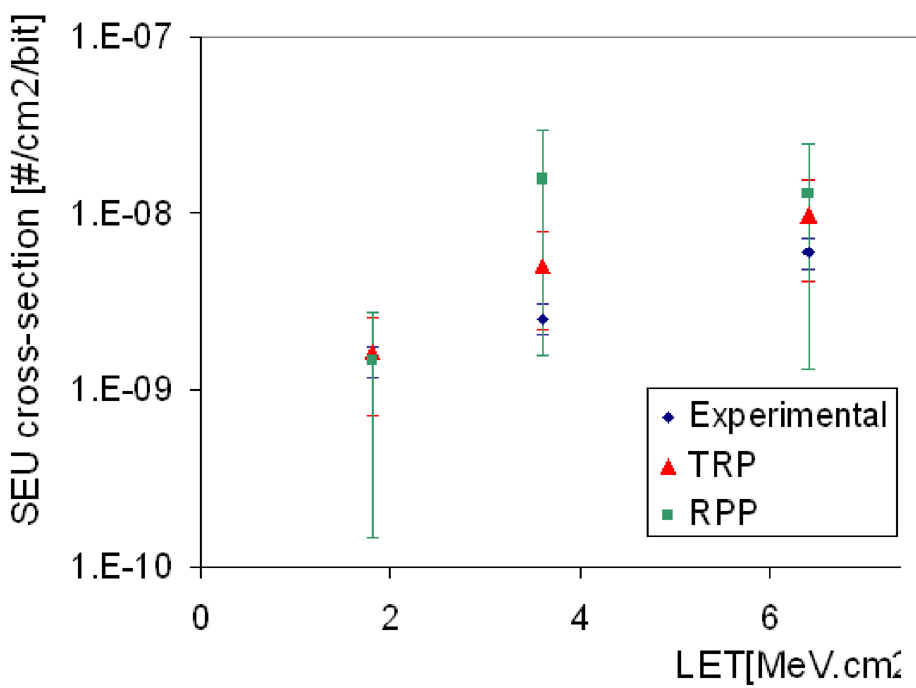
- Experimental Cocktail
- No. Events
- Credits
- Run SVFIT

Detailed SVFIT: Published papers

- RADECS 2011
- 10^6 evts

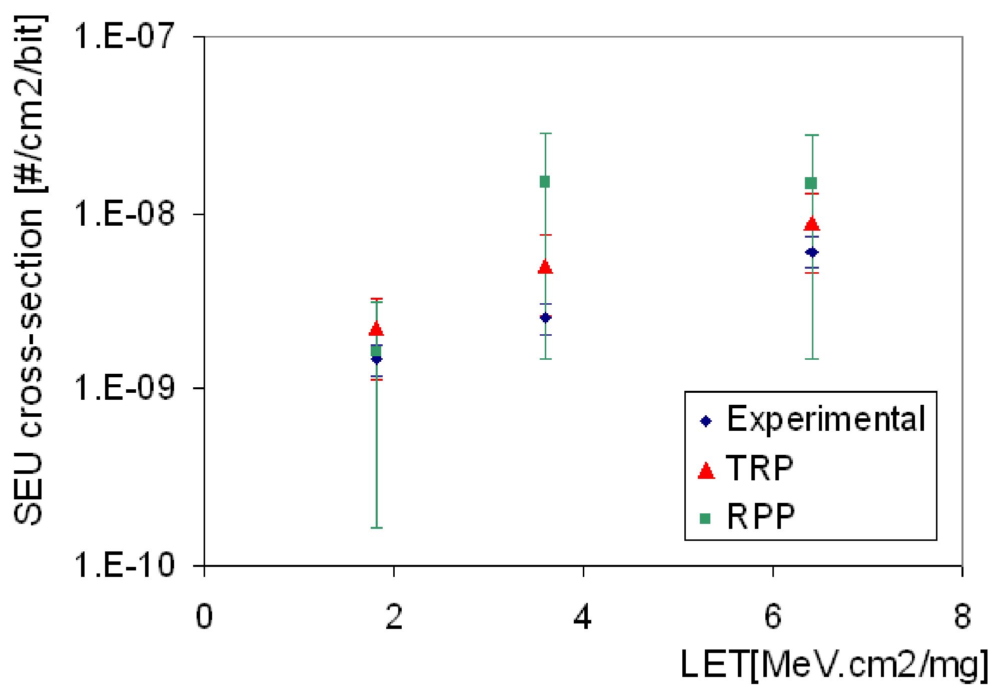


Engineering tool: ISSI1 SEU XS Reconstruction



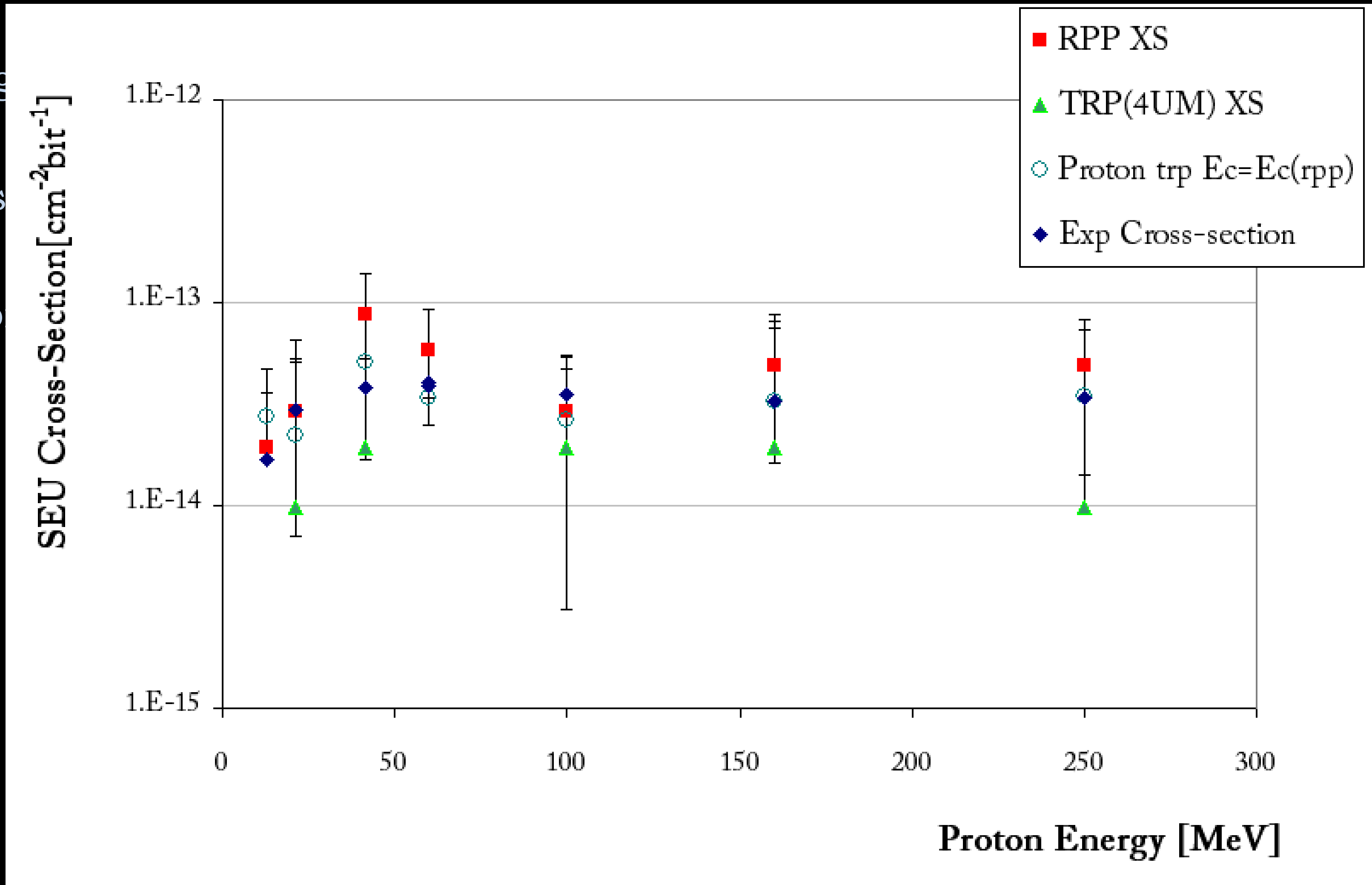
<- 10^3 evts

10^6evts ->



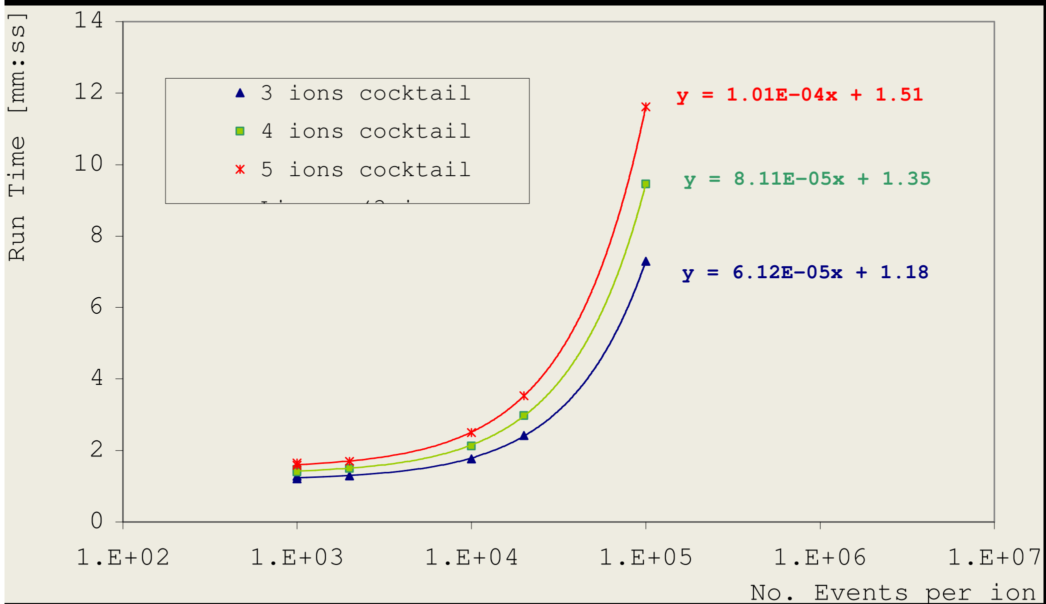
From Ion data to proton prediction

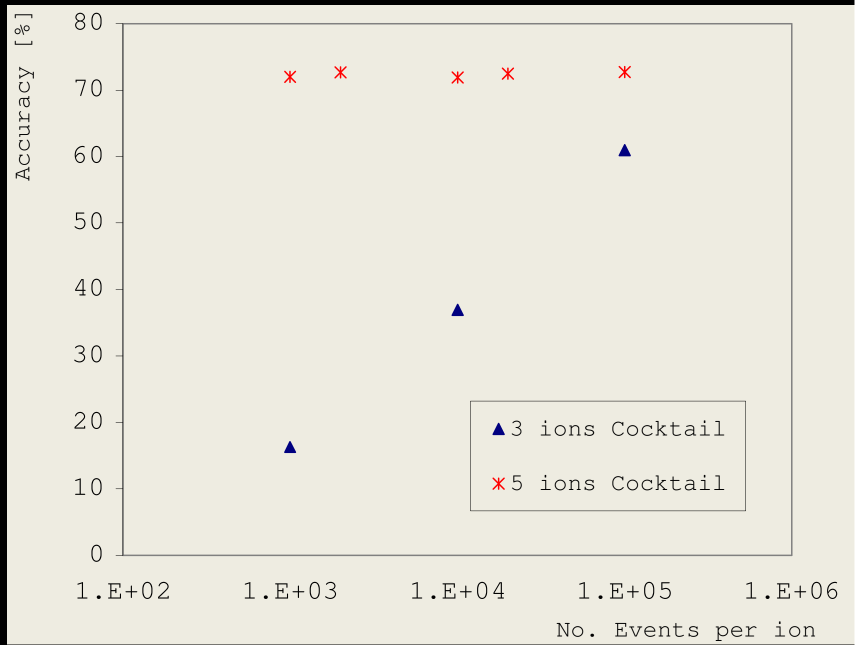
- Using
- The s
- Proto

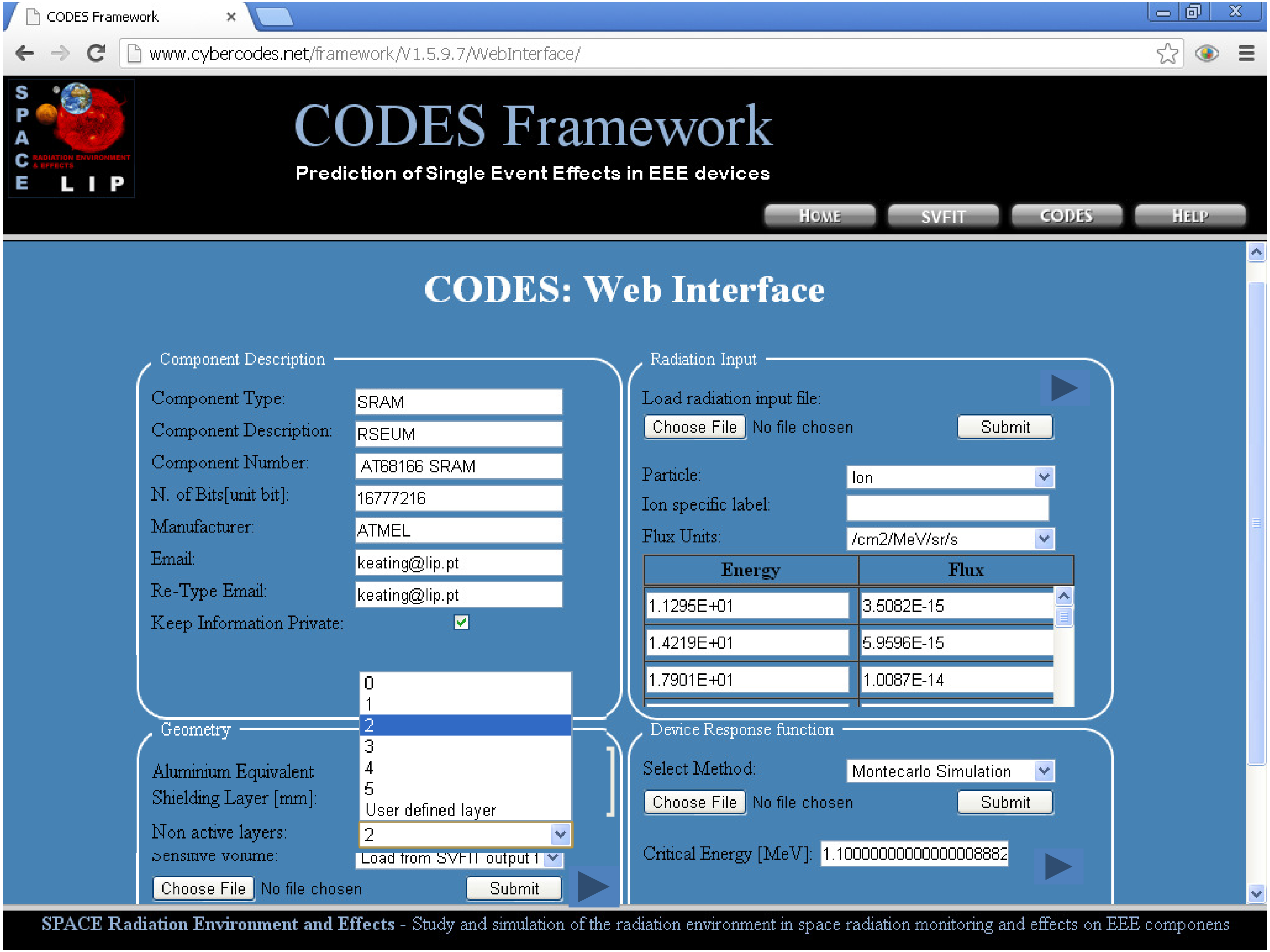


SVFIT working for different devices

- Tests have been made for the Reference SEU Monitor and SEL monitor devices



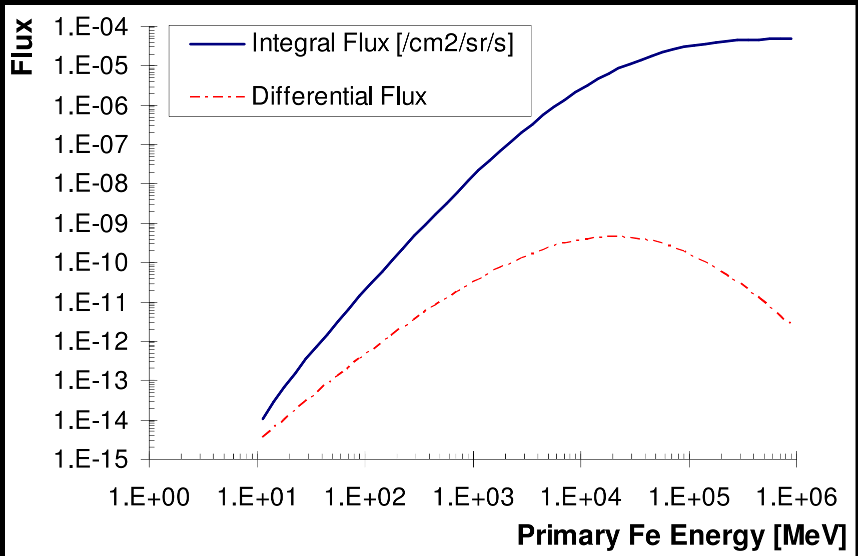



CODES Framework
www.cybercodes.net/framework/V1.5.9.7/WebInterface/
SPACE
RADIATION ENVIRONMENT & EFFECTS
LIP
CODES Framework
Prediction of Single Event Effects in EEE devices
HOME
SVFIT
CODES
HELP
CODES: Web Interface
Component Description
Component Type: SRAM
Component Description: RSEUM
Component Number: AT68166 SRAM
N. of Bits[unit bit]: 16777216
Manufacturer: ATMEL
Email: keating@lip.pt
Re-Type Email: keating@lip.pt
Keep Information Private:
Radiation Input
Load radiation input file:
Choose File No file chosen
Submit
Particle: Ion
Ion specific label:
Flux Units: /cm2/MeV/sr/s
Energy
Flux
1.1295E+01 3.5082E-15
1.4219E+01 5.9596E-15
1.7901E+01 1.0087E-14
Geometry
Aluminium Equivalent Shielding Layer [mm]:
0
1
2
3
4
5
User defined layer
Non active layers: 2
Sensitive volume: Load from SVFIT output f
Choose File No file chosen
Submit
Device Response function
Select Method: Montecarlo Simulation
Choose File No file chosen
Submit
Critical Energy [MeV]: 1.10000000000000008882
SPACE Radiation Environment and Effects - Study and simulation of the radiation environment in space radiation monitoring and effects on EEE componens

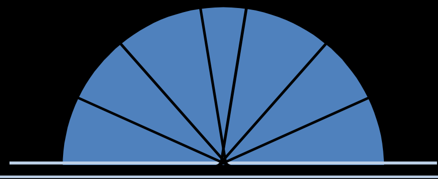
Normalization

According to the ICR

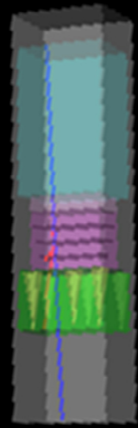
- Normalization is based on dMEREM/MARSREM normalization methods



Primary Integral Flux Normalization



Angular normalization



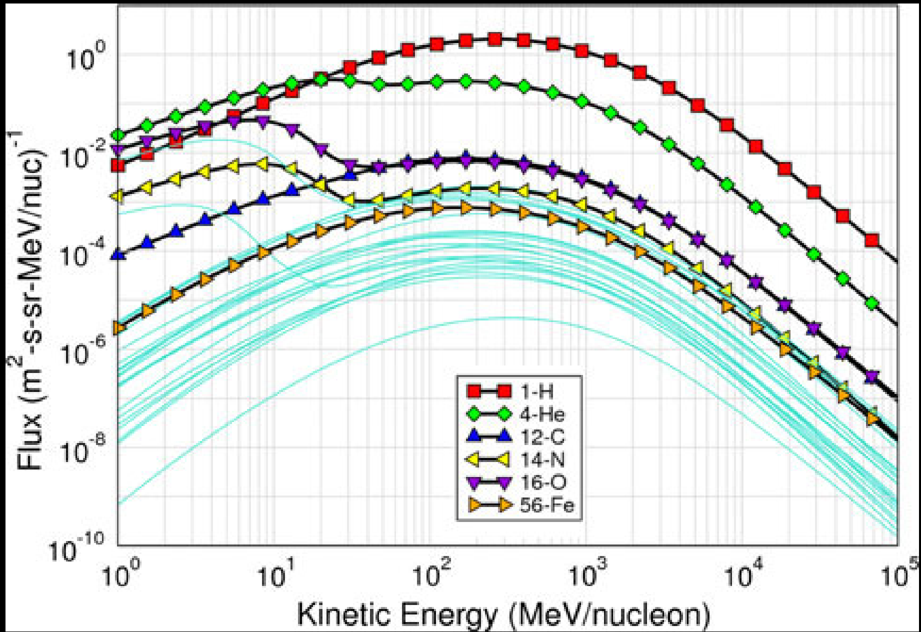
Geometrical acceptance

Theta Max

Total Flux Norm. = PrimFlxuNorm * GeomAccept * SolidAnglNorm

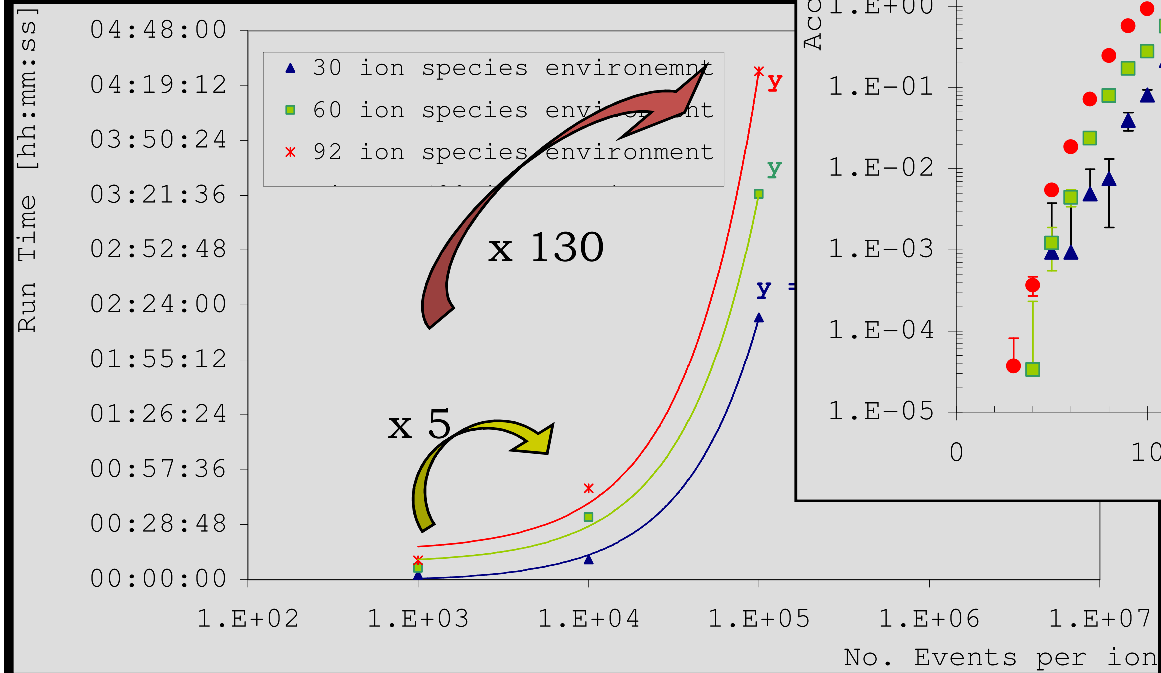
Full spectrum simulation

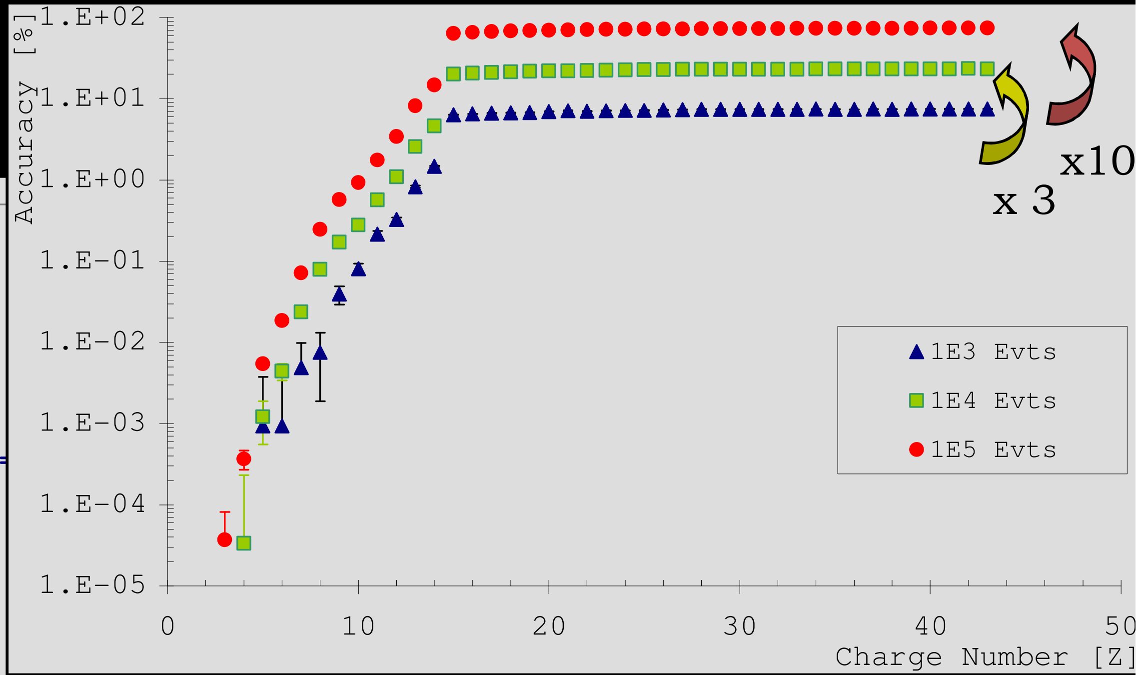
- CODES pre-processor takes inputs for several ions' energy spectra in SPENVIS format and others
- Computes individual contributions for SEE rates
- Outputs the total rate prediction



CODES Performance

- The framework is working properly under :
  - Windows Internet Explorer
  - Google Chrome
  - Firefox



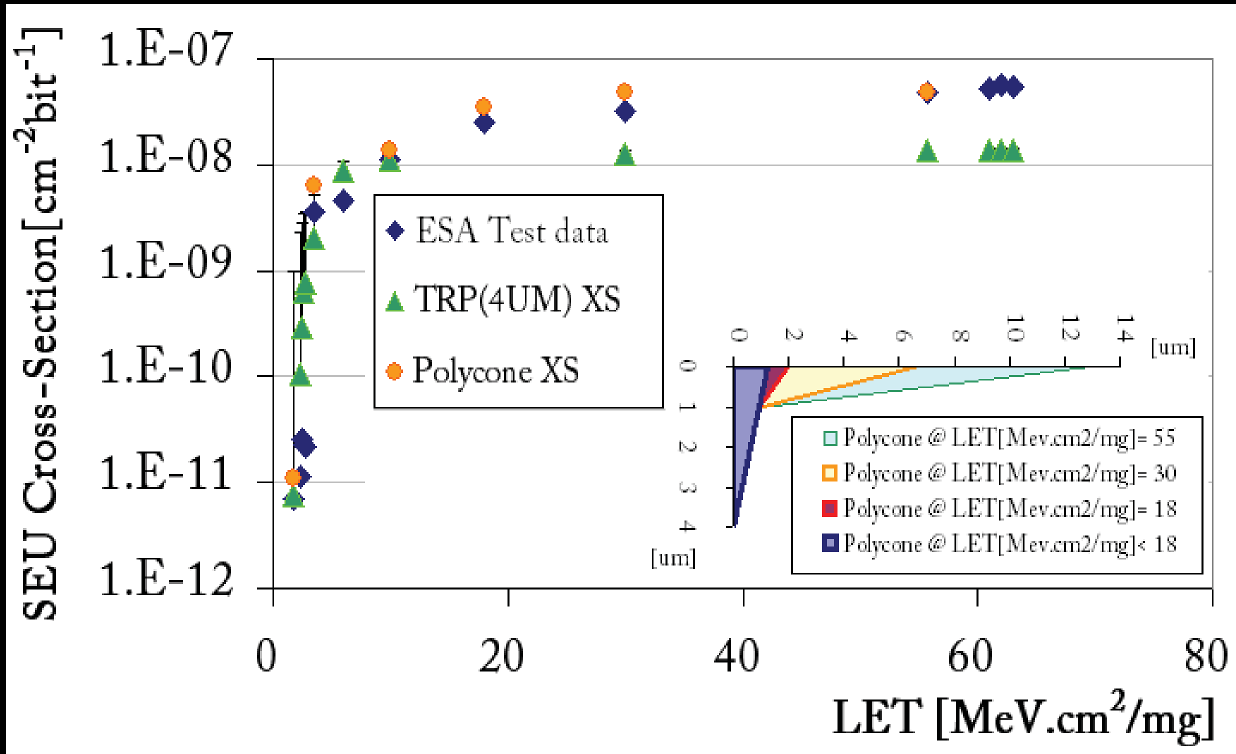


Additional models developed: that might be implemented

With SVFIT

Area increment above LET knee: Model & Results

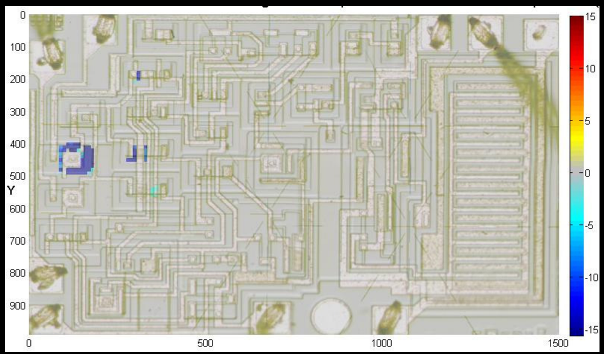
- Results published at RADECS 2011

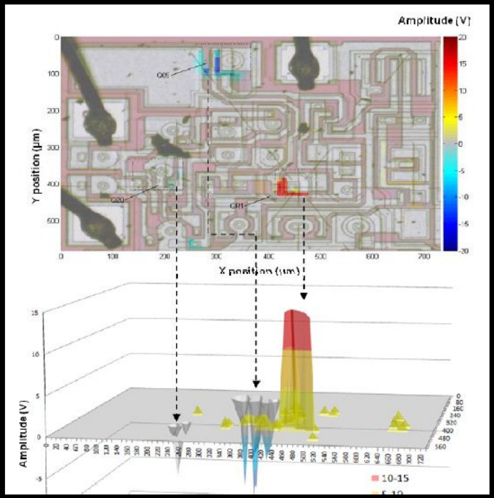


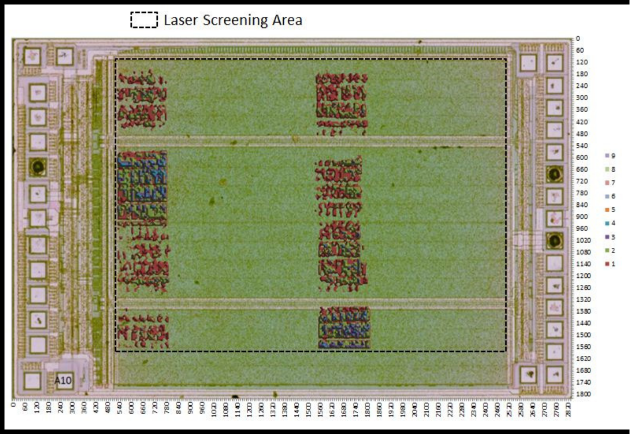
- Doi: 10.1109/RADECS.2011.6131414

Efficiency matrix from Laser maps

- The model of defining acomplex efficiency matrix was developed for SVFIT
- Objective : robust module for extraction from **laser maps** the charge **collection efficiency**
- SVFIT and CODES : benefit from the inclusion under the user-friendly interface







Images from of Isabel Lopez

Conclusion

- CODES modules: top level user friendly tool, with a web-interface
- Tests show the robustness of the tool: consistency, accuracy & run time

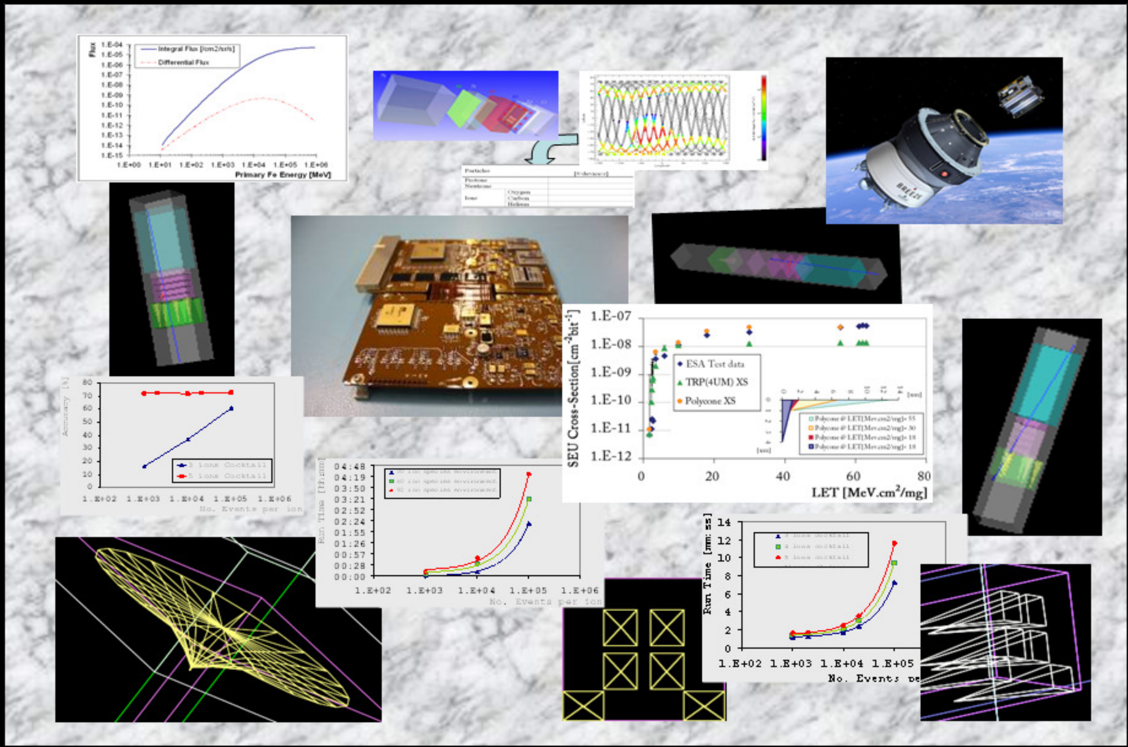
- Results show :
  - Very good reconstruction of device response function (3-5 ion cocktails): excellent SVFIT
  - Accuracy statistics independent (5 ion cocktails)
  - Run time : SV shape fit : (3 to 5 ions) - 2 geometries : btw 2-10 min statistics
  - Run time : SV shape and depth fir: (5 ions) - 6 geometries : ~ 30 minutes
  - mCODES higher independence from user definitions: stand. statistical methods and sCODES

Further Work

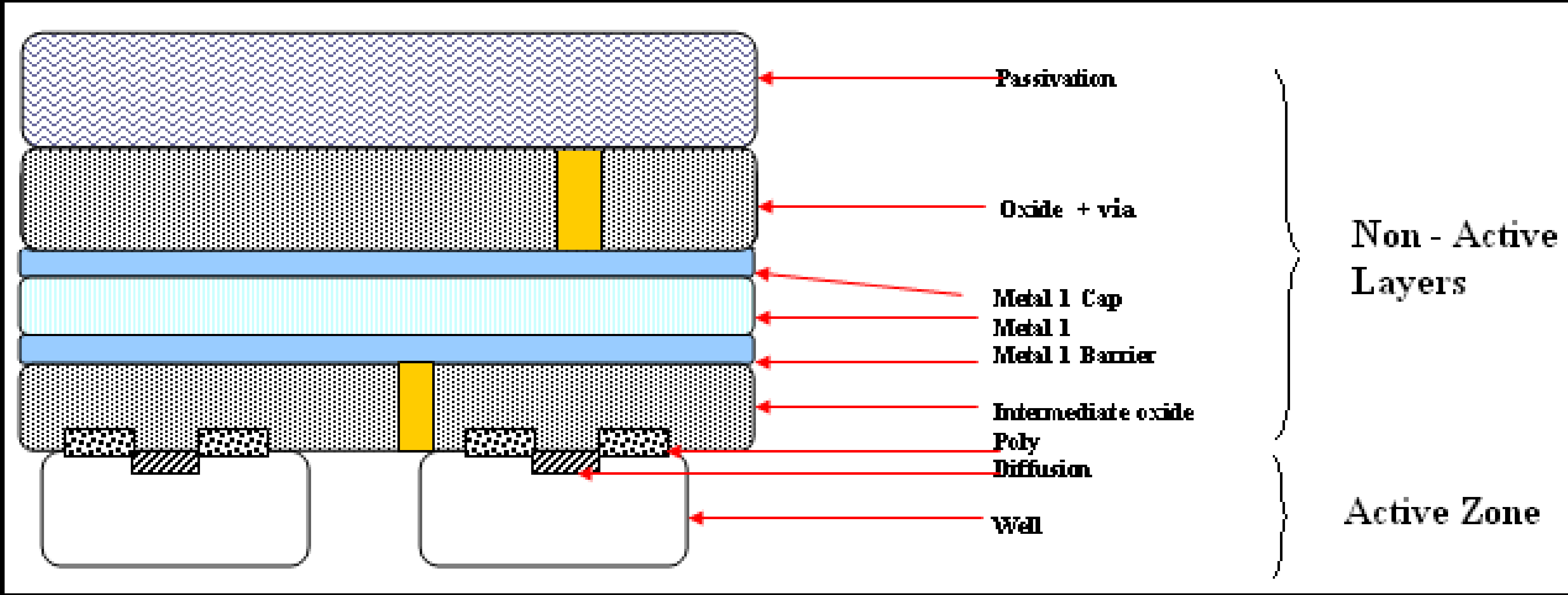
- Distribution of the tool
- Inclusion of ready-to-use developed models
- Incrementation of the Device Library
- Further models investigated: TRL needs to be increased

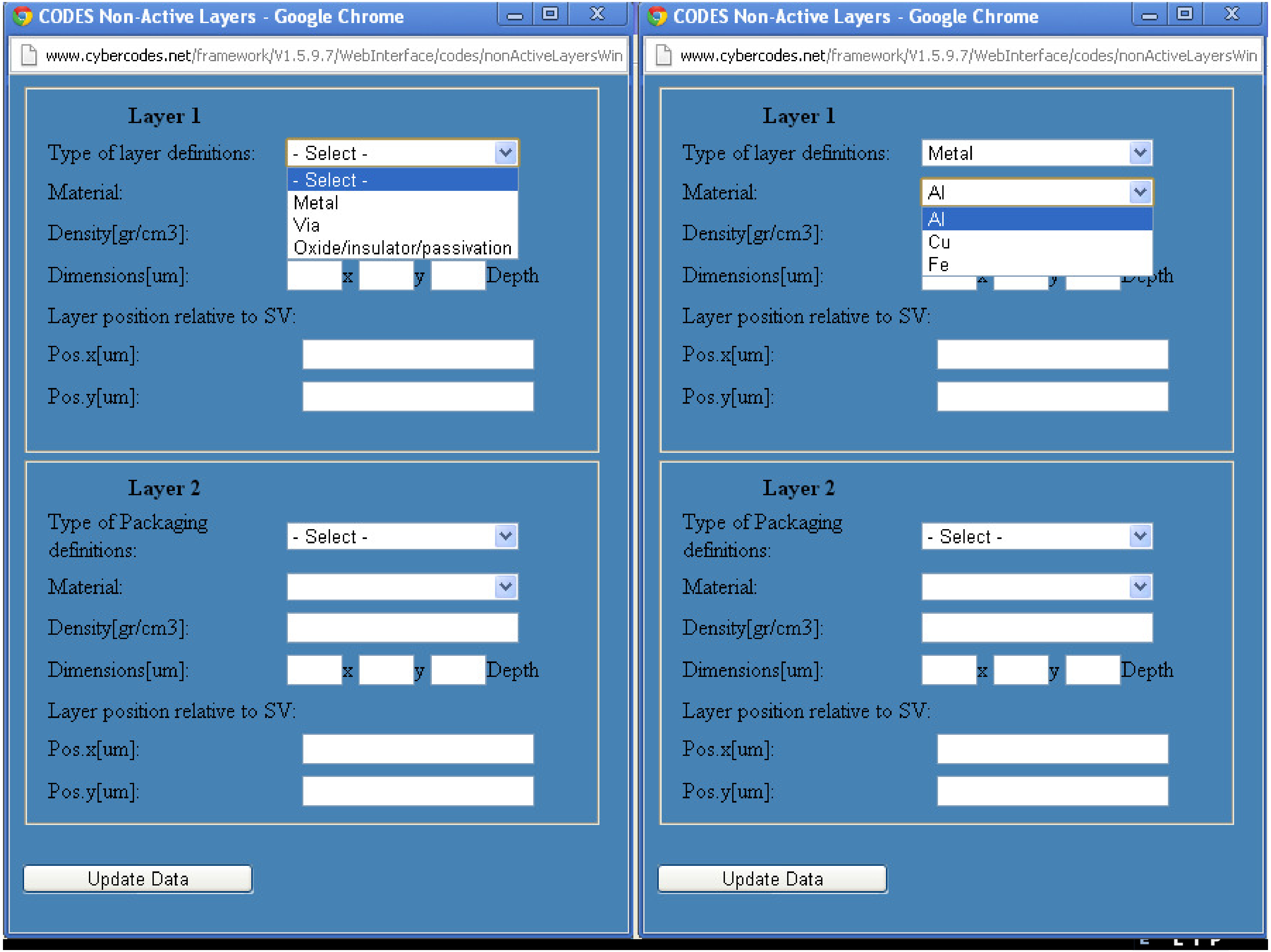
Thank you

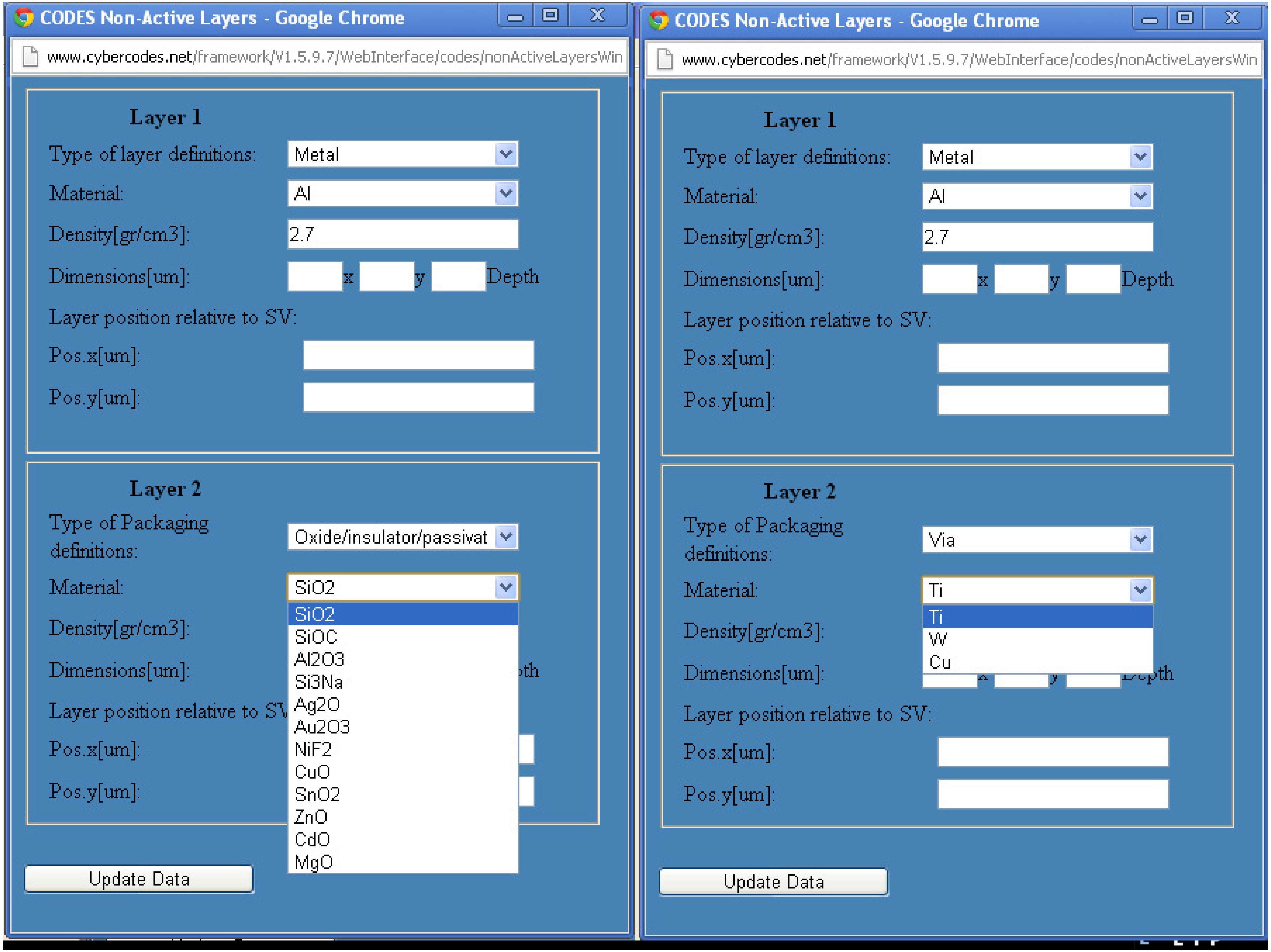
CODES — **Component Degradation**

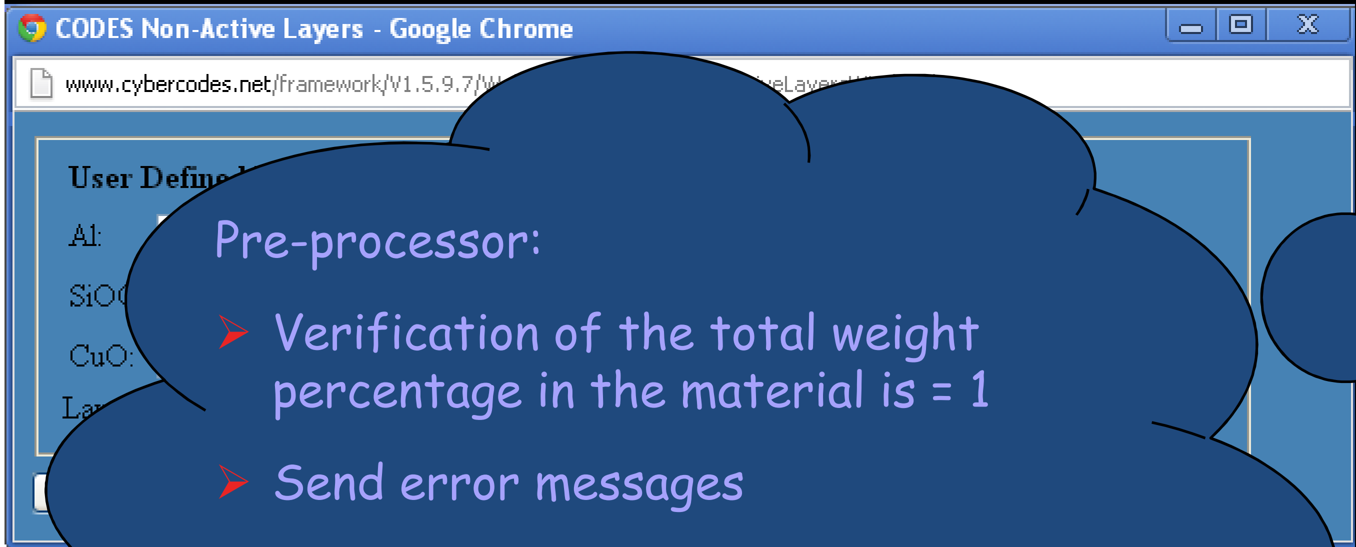


Additional slides


Passivation
Oxide + via
Metal 1 Cap
Metal 1
Metal 1 Barrier
Intermediate oxide
Poly
Diffusion
Well
Non - Active Layers
Active Zone


CODES Non-Active Layers - Google Chrome
www.cybercodes.net/framework/V1.5.9.7/WebInterface/codes/nonActiveLayersWin
Layer 1
Type of layer definitions:
- Select -
- Select -
Metal
Via
Oxide/insulator/passivation
Material:
Density[gr/cm3]:
Dimensions[um]:
x
y
Depth
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Layer 2
Type of Packaging definitions:
- Select -
Material:
Density[gr/cm3]:
Dimensions[um]:
x
y
Depth
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Update Data
CODES Non-Active Layers - Google Chrome
www.cybercodes.net/framework/V1.5.9.7/WebInterface/codes/nonActiveLayersWin
Layer 1
Type of layer definitions:
Metal
Material:
Al
Al
Cu
Fe
Density[gr/cm3]:
Dimensions[um]:
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Layer 2
Type of Packaging definitions:
- Select -
Material:
Density[gr/cm3]:
Dimensions[um]:
x
y
Depth
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Update Data


CODES Non-Active Layers - Google Chrome
www.cybercodes.net/framework/V1.5.9.7/WebInterface/codes/nonActiveLayersWin
Layer 1
Type of layer definitions: Metal
Material: Al
Density[gr/cm3]: 2.7
Dimensions[um]: x y Depth
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Layer 2
Type of Packaging definitions: Oxide/insulator/passivat
Material: SiO2
SiO2
SiOC
Al2O3
Si3Na
Ag2O
Au2O3
NiF2
CuO
SnO2
ZnO
CdO
MgO
Density[gr/cm3]:
Dimensions[um]:
Layer position relative to SV
Pos.x[um]:
Pos.y[um]:
Update Data
CODES Non-Active Layers - Google Chrome
www.cybercodes.net/framework/V1.5.9.7/WebInterface/codes/nonActiveLayersWin
Layer 1
Type of layer definitions: Metal
Material: Al
Density[gr/cm3]: 2.7
Dimensions[um]: x y Depth
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Layer 2
Type of Packaging definitions: Via
Material: Ti
Ti
W
Cu
Density[gr/cm3]:
Dimensions[um]:
Layer position relative to SV:
Pos.x[um]:
Pos.y[um]:
Update Data



Pre-processor:

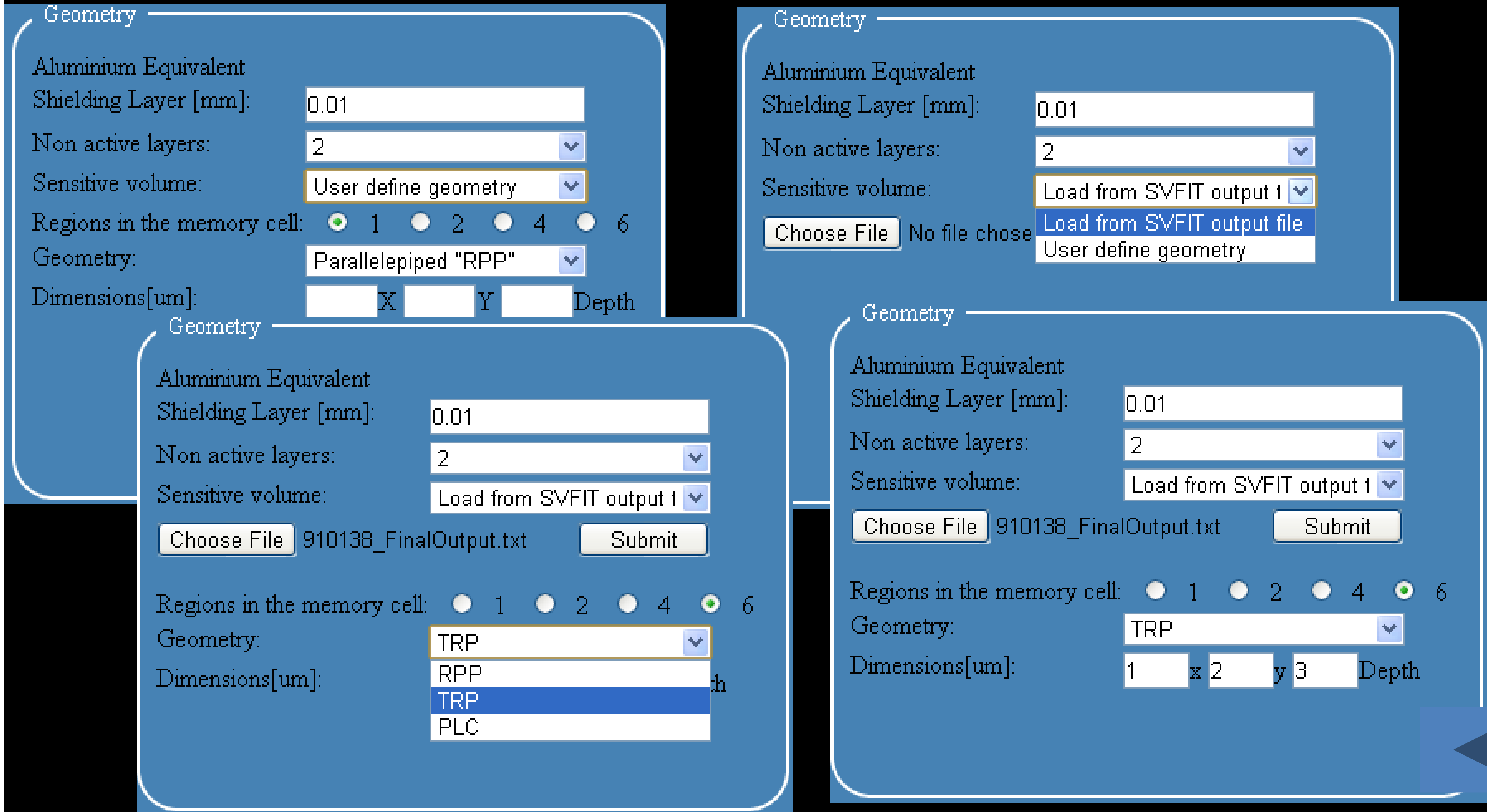
- Verification of the total weight percentage in the material is = 1
- Send error messages
- Compute total density
- Compute layer positions in relation to device structure
- Write NALFile.txt with NAL table
- ✓ All have been verified

Software CYBERoffice INFORMÁTICA E SERVIÇOS

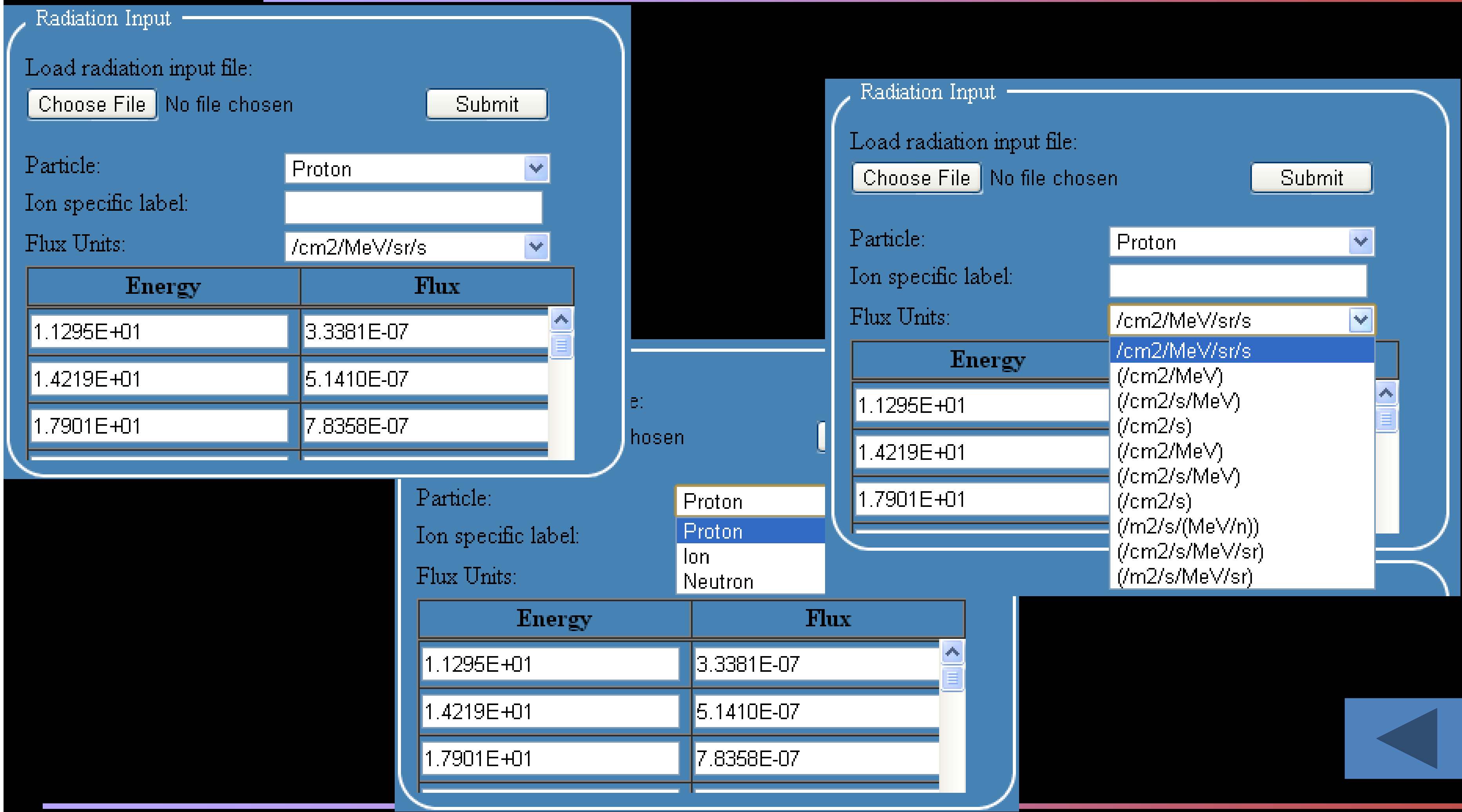
CdO	MgO	Density [g/cm3]	Dimension X [um]	Y [um]	Z [um]	Position XPos [um]	YPos [um]	ZPos [um]

LIP & CYBEROFFICE

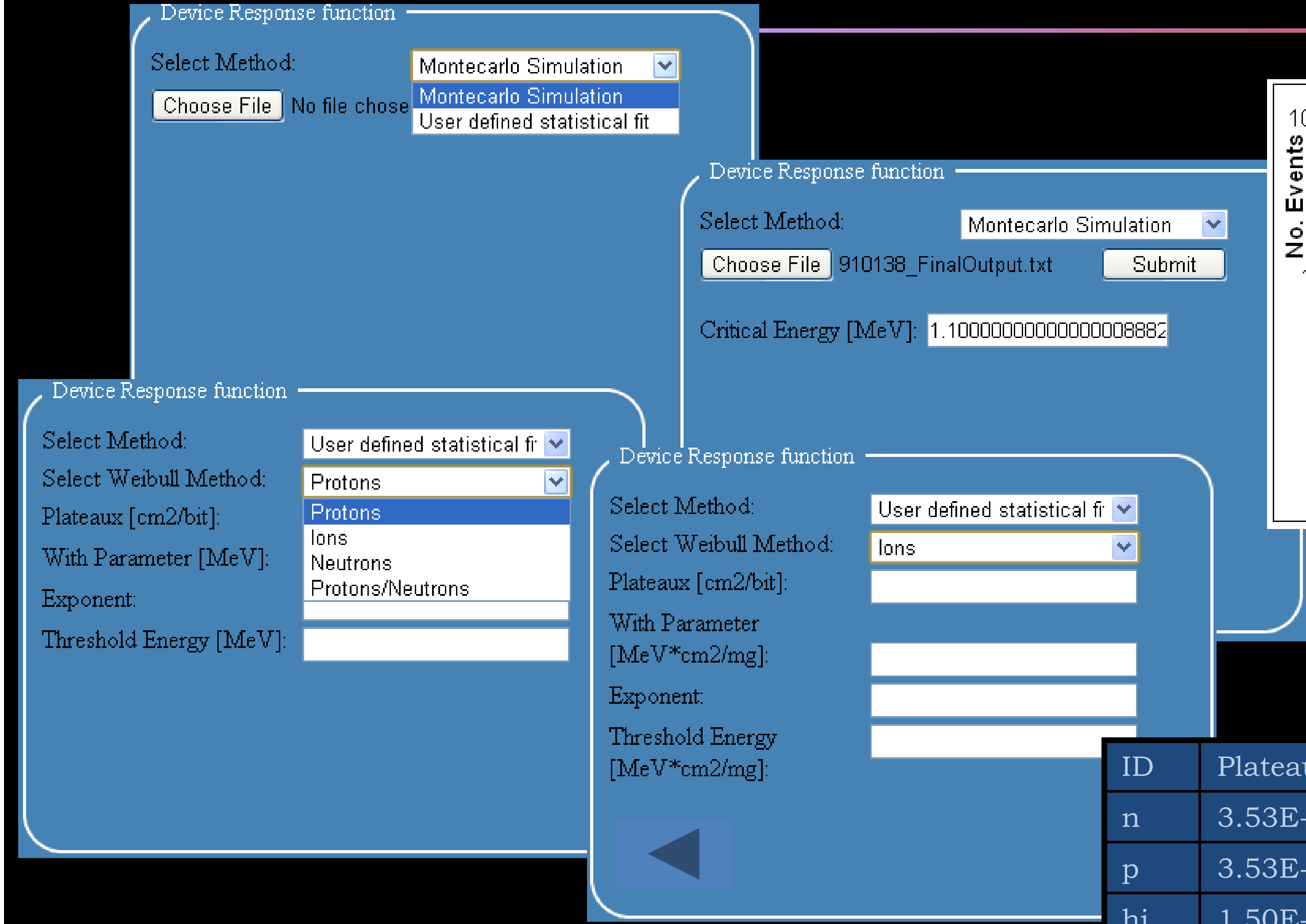
SV Volume definition

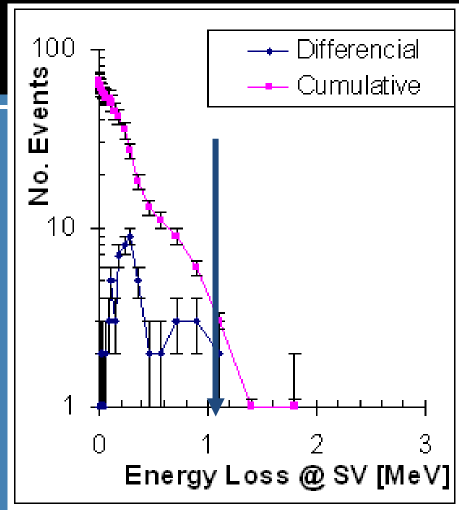


Radiation Input File



Device Response Function

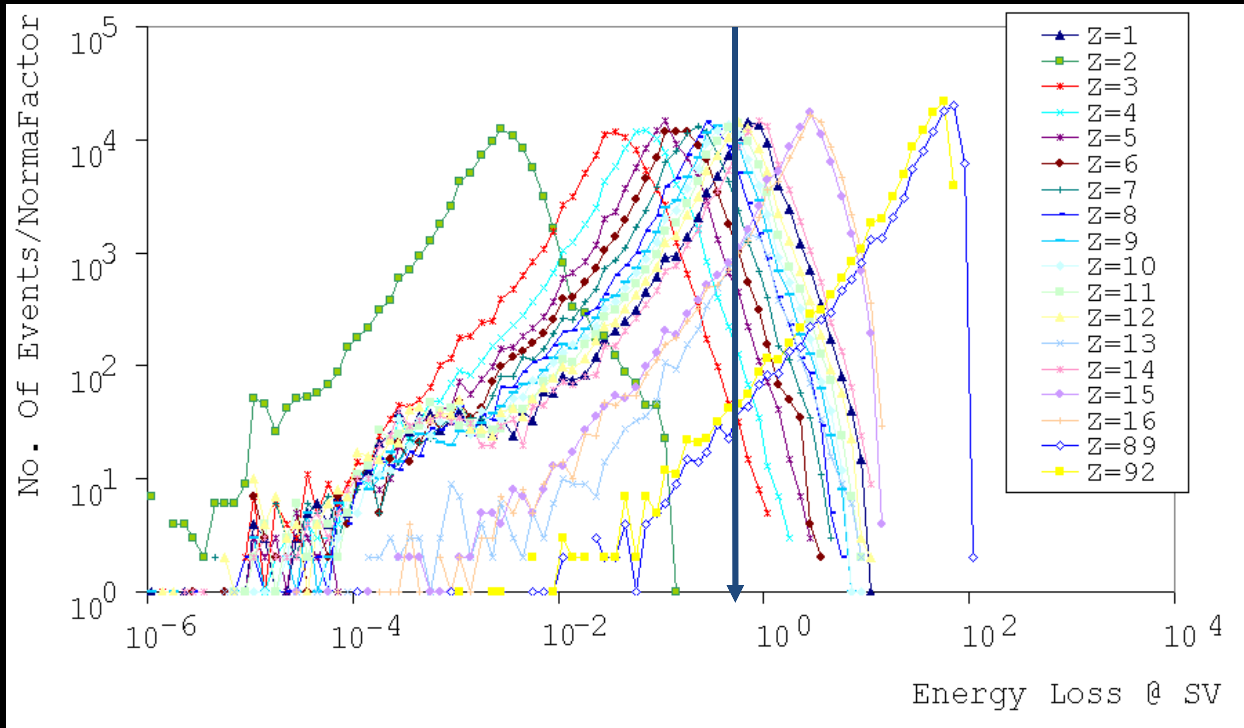




SEU = No. Event * NormF

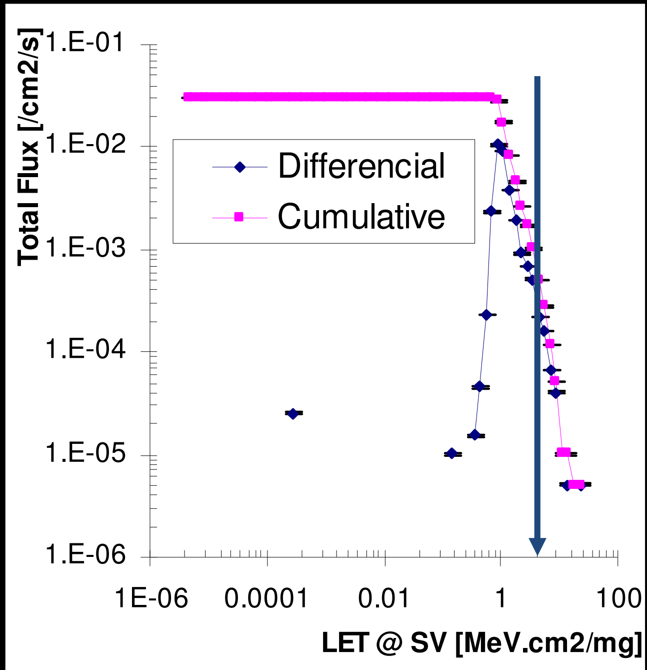
ID	Plateaux	With	Exp	Thres.
n	3.53E-14	4	1	10
p	3.53E-14	4	1	10
hi	1.50E-07	65	1.4 7	1.2

SEU calculation with mCODES



SEU Rate = No Evts (Edep > Ec)/NGen * Total Flux * Active Area

SEU calculation with sCODES



ID	Plateaux	With	Exp	Thres.
n	3.53E-14	4	1	10
p	3.53E-14	4	1	10
hi	1.50E-07	65	1.47	2

SEU Rate = No Evts (LET> Th)/NGen * Total Flux * <SEU_XS>

SVFIT automatic/iterative

- Modular iterative tool
- Microdosimetry Monte-Carlo
- Device sensitive volume: cha collection.
- Input parameters:
  - Ion cocktails description
  - Irradiation test data
- SEU threshold definition
- SV shape modulation
- Output:
  - best SV shape to fit ion test
  - Threshold Energy loss for S
  - Reconstructed SEE XS curv

Results

```
SVFIT interactive mode final results
Best geometry description
User input data:
For (6) SV volumes
SVx 1 um
SVy 0.81 um
SVz 3 um  Depth +/- 10%                         uncertainty

Best geometry shape: TRP
Accuracy: 74.3131

***********************************************;
Cross section destail for different geometries;
***********************************************;
SVdepth   SVz       3 um

****************************************;
LET;SEE XS (exp);SEEXS (rpp);SEEXS(trp);
****************************************;
1.7;6.9700E-12;1.65240000000000020821e-09 ;2.23560000000000042767e-09 ;
3.5;3.64262E-9;0 ;7.38720000000000112547e-09 ;
6;4.63064E-9;1.50660000000000007063e-08 ;1.04976000000000006416e-08 ;
10;1.12421E-8;1.53576000000000024704e-08 ;1.21500000000000012634e-08 ;
30;3.27837E-8;1.48716000000000022875e-08 ;1.41912000000000020315e-08 ;
****************************************;
Best geometry: TRP;Accuracy: 72.7144%;

SVdepth   SVz+10% uncertainty3.3 um
****************************************;
LET;SEE XS (exp);SEEXS (rpp);SEEXS(trp);
****************************************;
1.7;6.9700E-12;1.06920000000000007147e-08 ;2.52720000000000012381e-09 ;
3.5;3.64262E-9;1.57464000000000026167e-08 ;7.38720000000000112547e-09 ;
6;4.63064E-9;1.52604000000000007795e-08 ;1.06920000000000007147e-08 ;
10;1.12421E-8;1.51632000000000023972e-08 ;1.18584000000000011536e-08 ;
30;3.27837E-8;0 ;1.55520000000000025436e-08 ;
****************************************;
Best geometry: TRP;Accuracy: 74.3131%;

SVdepth   SVz-10% uncertainty2.7 um
****************************************;
LET;SEE XS (exp);SEEXS (rpp);SEEXS(trp);
****************************************;
1.7;6.9700E-12;1.34136000000000017389e-08 ;1.55520000000000017164e-09 ;
3.5;3.64262E-9;0 ;6.51240000000000079628e-09 ;
6;4.63064E-9;1.30248000000000015926e-08 ;1.03032000000000005684e-08 ;
10;1.12421E-8;0 ;1.10808000000000000861e-08 ;
30;3.27837E-8;1.36080000000000001812e-08 ;1.39968000000000019583e-08 ;
****************************************;
Best geometry: TRP; Accuracy: 72.8557%;
```