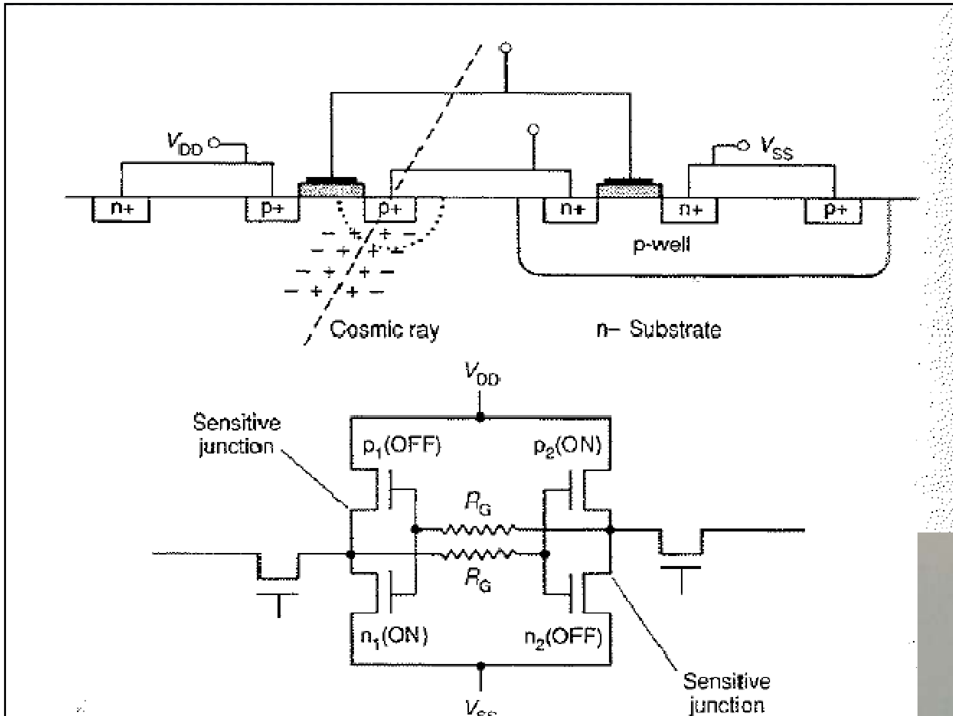
Engineering Department

Event by event energy deposition distribution in FLUKA

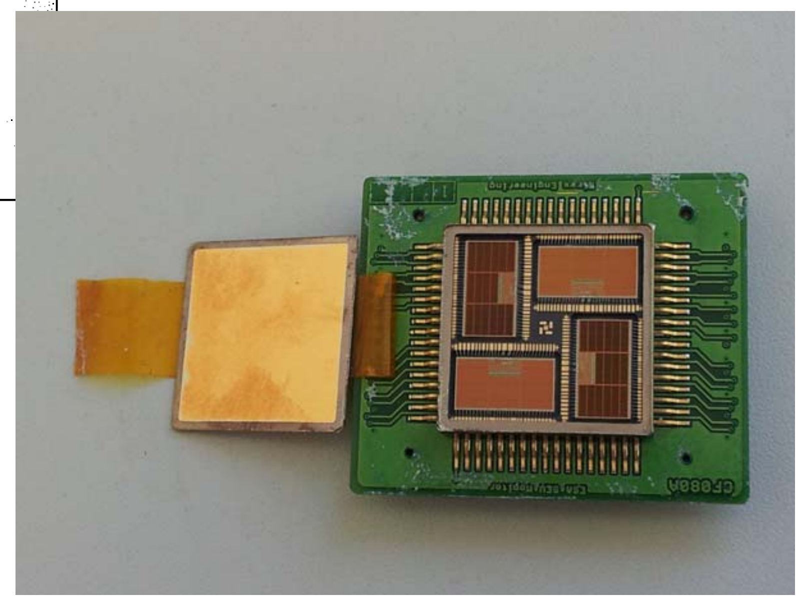
Rubén García Alía

(PhD student at CERN and UM2, under the supervision of M. Brugger, K. Røed, F. Saigne and F. Wrobel)

General Context



- Use of SRAM memories as SEU counters to monitor the radiation environment



- Importance of an MC tool to simulate not only the radiation field but also the energy deposition in the device

Nature of SEEs

- "Single event effects (SEEs) arise through the action of a single ionizing particle as it penetrates the sensitive node of a device." *(Single Event Effects in Aerospace, E. Petersen)*
- Due to their stochastic nature, SEE analysis using Monte Carlo tools requires the scoring of the energy deposition on an event by event basis in the regions of interest (sensitive volume, SV).
- For indirect energy deposition (protons, neutrons) the energy deposition events of interest will often be very rare.

Available tool in FLUKA for event by event scoring

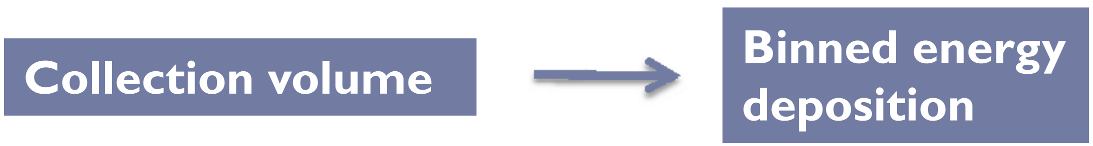
- EVENTDAT card: *Prints event by event the scored star production and/or energy deposition in each region.*
- Limitations:
  - writes a line for each energy deposition event, resulting in very large output files (notably if rare events are of interest)
  - due to its event by event nature, the output of a biased run will not be meaningful

Available tool in FLUKA for event by event scoring (II)

- DETECT card: *Scores energy deposition on an event basis (detector).*
- Limitations:
  - only one DETECT card is permitted per input, with limited detection volumes
  - the energy histogramming is set to 1024 bins
  - it is not possible to link the AUXSCORE to it for filtering purposes
  - it will only provide meaningful results when FLUKA is used in a completely analogue mode

Use of user routines for event by event energy deposition scoring

- Motivated by the limitations introduced before, a set of user routines were put together (by Ketil Røed, University of Oslo) in order to score and histogram the energy deposition on an event by event basis in a user-flexible way.



- The core of this tool consists of:
  - the comscw.f user routine, called after every energy deposition event
  - the usreou.f user routine, called after each primary particle, taking the energy deposition information from comscw.f, processing it and filling it in a histogram

Input cards

- The USRICALL cards are used to request histogram scoring of energy deposition events in the input file:

USRICALL	#1: 144.	#2: 1E-6	#3: 1.0E-1
sdum: CV1	#4: -6.0	#5: 1.0	#6: 0.0
	#7: 100.	#8:	#9:
	#10:	#11:	#12:

WHAT(1): NBINSPRE: number of histogram bins
WHAT(2): ELOWPRE: Lowest energy
WHAT(3): EHIGHPRE: Highest energy
WHAT(4): IPARTPRE: requested particle type
WHAT(5): HTYPEPRE: histogram type (If 1 then log, else lin)
WHAT(6): IFILTPRE: Additional filter parameter
SDUM: RNAMEPRE: Name of region where the energy deposition events are to be collected.
Continuation card:
WHAT(1): ICONTDET: Number of consecutive regions to be activated.
WHAT(2): INOLAT1: Lattice number of first lattice
WHAT(3): INOLAT2: Lattice number of last lattice
WHAT(4-6): Not used
SDUM: &n\

Detector definition:
region, energy binning, particle filtering

Input cards (II)

- A USERBIN card is included in the input with SDUM=ECV as keyword in the comscw.f routine to enable event by event energy deposition scoring.

USRBIN		Unit: 30 BIN ▼	Name: ECV
Type: Region ▼	R1from: CV1 ▼	R1to: CV100 ▼	Step1:
Part: ENERGY ▼	R2from: ▼	R2to: ▼	Step2:
	R3from: ▼	R3to: ▼	Step3:

- A USERDUMP and a USERWEIG card are included in order to enable access to the mgdraw.f and comscw.f routines respectively.

Enable access and call to mgdraw.f			
USERDUMP	Type: Dump ▼	Unit: ▼	File:
	What: Complete ▼	Score: All ▼	Dump: User Defined ▼
enable access and call to comscw.f			
USERWEIG	Weight: ▼	Resnuclei: No weight ▼	Density: COMSCW+ ▼

Histogram initialization and interaction information

- The usrini.f routine, called every time the USRICALL card is found in the input stream, initializes the histogram scoring.
- The histogram.f routine contains the INITHIST (called from usrini.f at the beginning of a run) and FILLHISTOGRAM (called from usreou.f at the end of each primary event) subroutines.
- The mgdraw.f routine (activated by the USERDUMP card in the input) is called after every interaction and keeps track of the information related to the particle generating the interaction (very important for energy deposited by e^+, e^- and photons).

Requested energy deposition information and histogram fill

- The comscw.f routine (activated by the USRWEIGH card in the input) is called every time an energy deposition event takes place:
  - a flag is set in order to indicate that an energy deposition event has occurred in a region of interest.
  - in this case, the relevant information about the event (deposited energy, collection region, particle type) is stored in the tables defined in the edepcommon common.
- The usreou.f routine is called after each primary event and takes the information from the energy deposition table, processing it and storing it in the respective histograms through the FILLHISTOGRAM subroutine.

Output

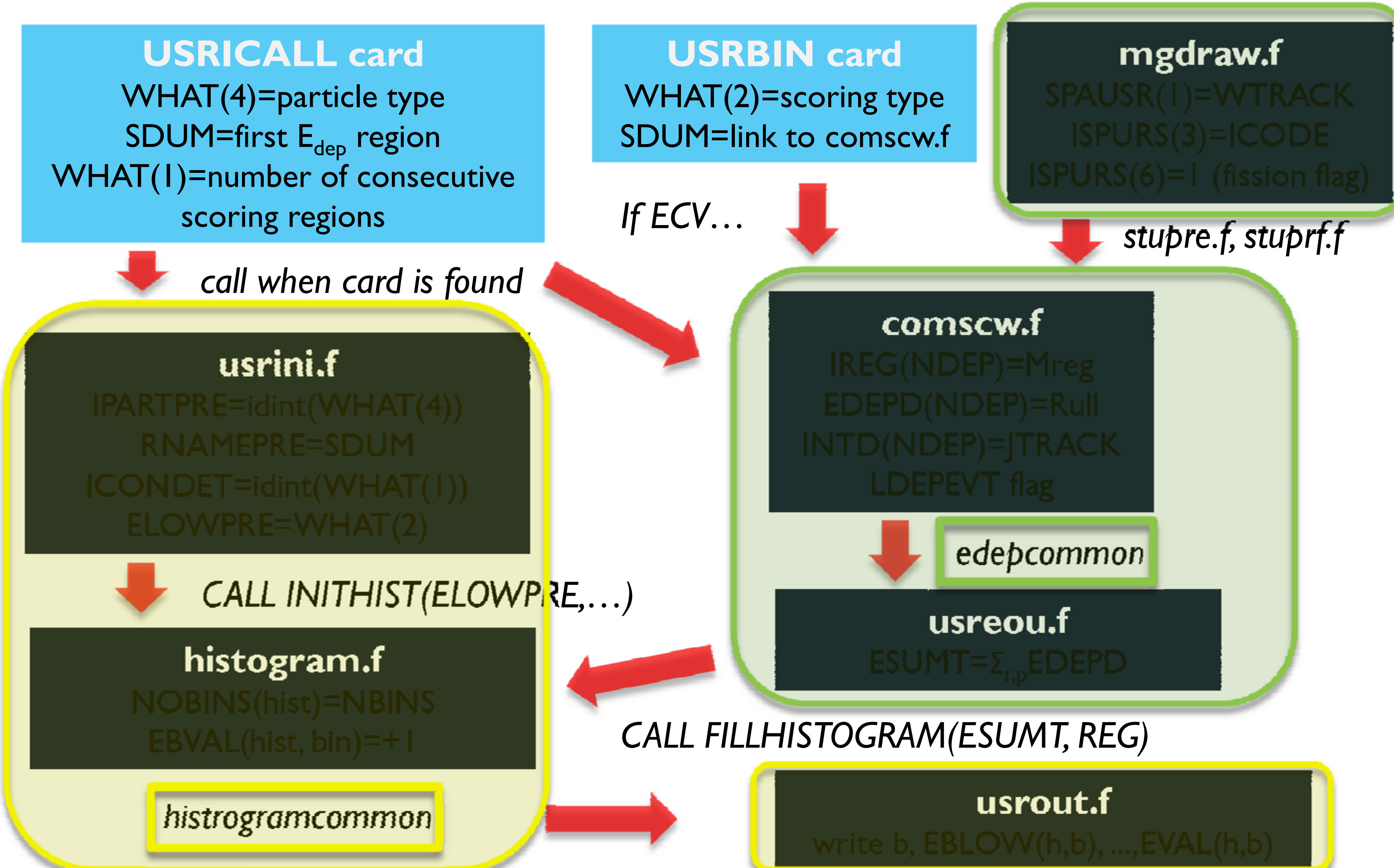
- The usrout.f routine is called at the end of a complete simulation run and loops through all the requested histograms printing the result to unit 50 (to be impemented as input option in the USRICALL card).

```
#HistogramNo:   1.
#LatticeNumber:  0
#RegionNumber:  19
#DetectorName: CV1
#ParticleFilter:  99
#FilterId:  0
#NumberOfBins:  144
#PrimaryWeight:   100000000.
#TotalEntries:  26994
#BinNo ELOW EHIGH VALUE
 1.   1.E-06   1.10069417E-06   2.19E-06
 2.   1.10069417E-06   1.21152766E-06   2.53E-06
 3.   1.21152766E-06   1.33352143E-06   3.27E-06
 4.   1.33352143E-06   1.46779927E-06   4.36E-06
 5.   1.46779927E-06   1.6155981E-06   5.43E-06
 6.   1.6155981E-06   1.77827941E-06   1.089E-05
 7.   1.77827941E-06   1.95734178E-06   1.001E-05
 8.   1.95734178E-06   2.15443469E-06   1.654E-05
 9.   2.15443469E-06   2.37137371E-06   1.903E-05
 10.   2.37137371E-06   2.61015722E-06   2.185E-05
 11.   2.61015722E-06   2.87298483E-06   2.141E-05
 12.   2.87298483E-06   3.16227766E-06   2.211E-05
 13.   3.16227766E-06   3.48070059E-06   2.104E-05
 14.   3.48070059E-06   3.83118685E-06   1.922E-05
 15.   3.83118685E-06   4.21696503E-06   1.614E-05
```

Output example:

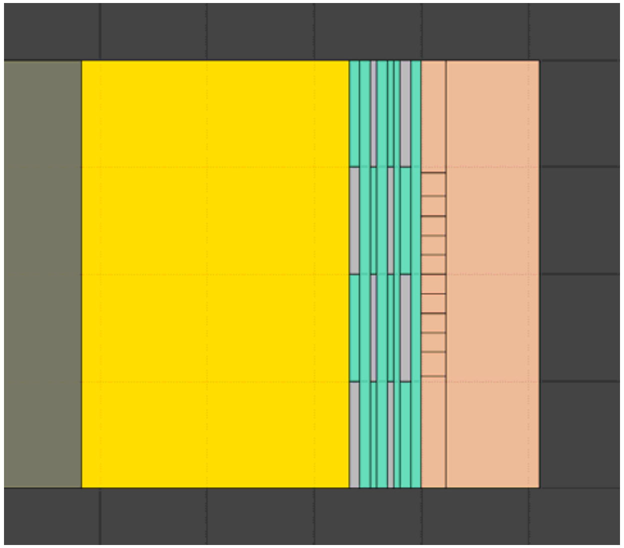
- 1E+8 primaries (13 MeV protons) on 40 x 40 um^2 with a collection surface of 0.36 um^2. Expected number of particles reaching the SV:
  $N_{int}=N_o(S_{SV}/S_{beam})=2.48E+4$
- LET(13 MeV p in Si)=2.84 $\cdot 10^{-2}$ MeVcm^2/mg.
  $E_{dep}\sim 4.1$ keV ($>E_{low}$)

Schematic overview



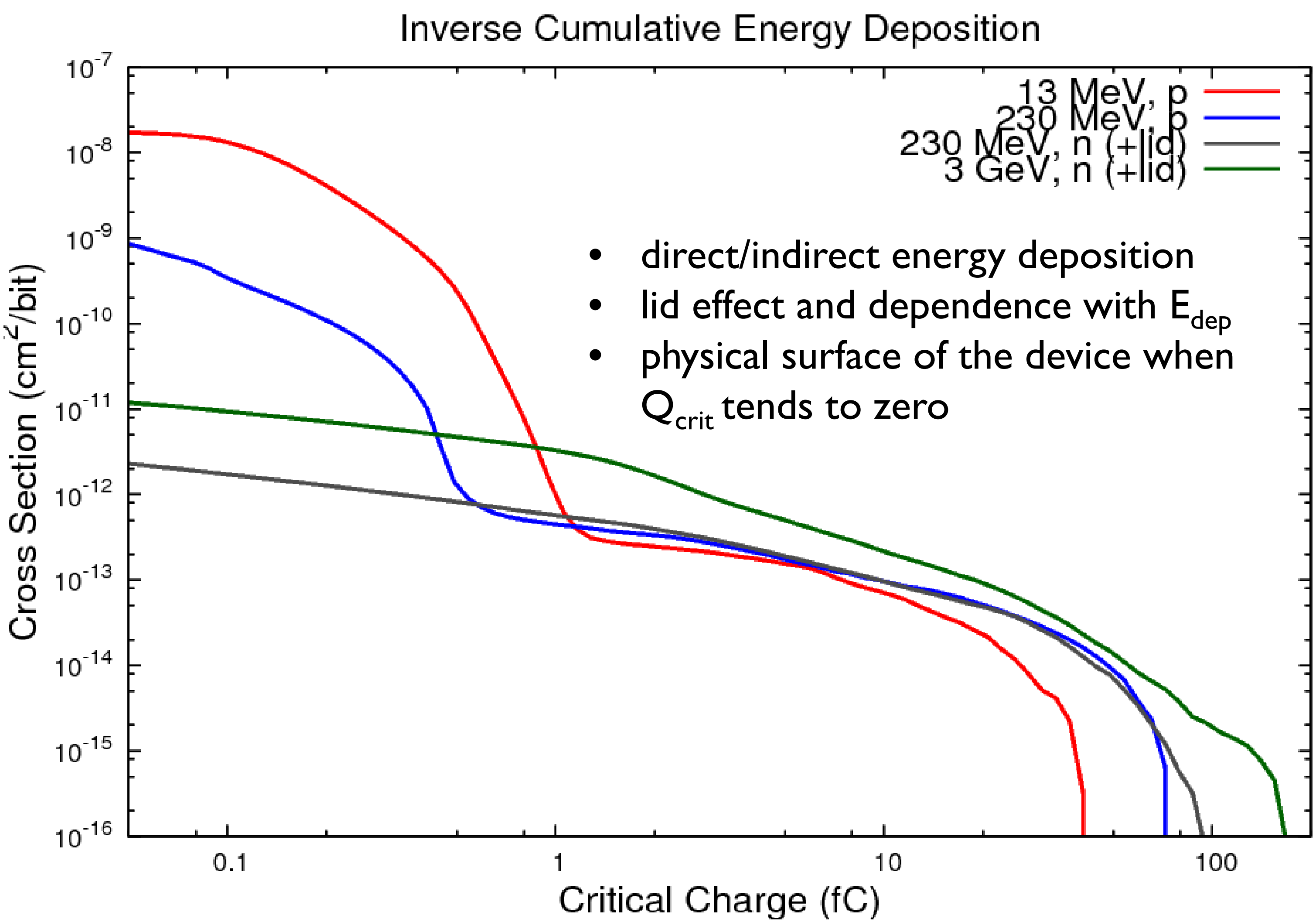
Practical example: RPP model

- Collection volume defined as an RPP (representing the drift area of a pn junction. If $Q_{dep} > Q_{crit}$ an event occurs)
- Representation of a commercial 250 nm SRAM technology. The SV can be typically take as a cube of $V=0.25\ \mu m^3$ [Roche, 2003].



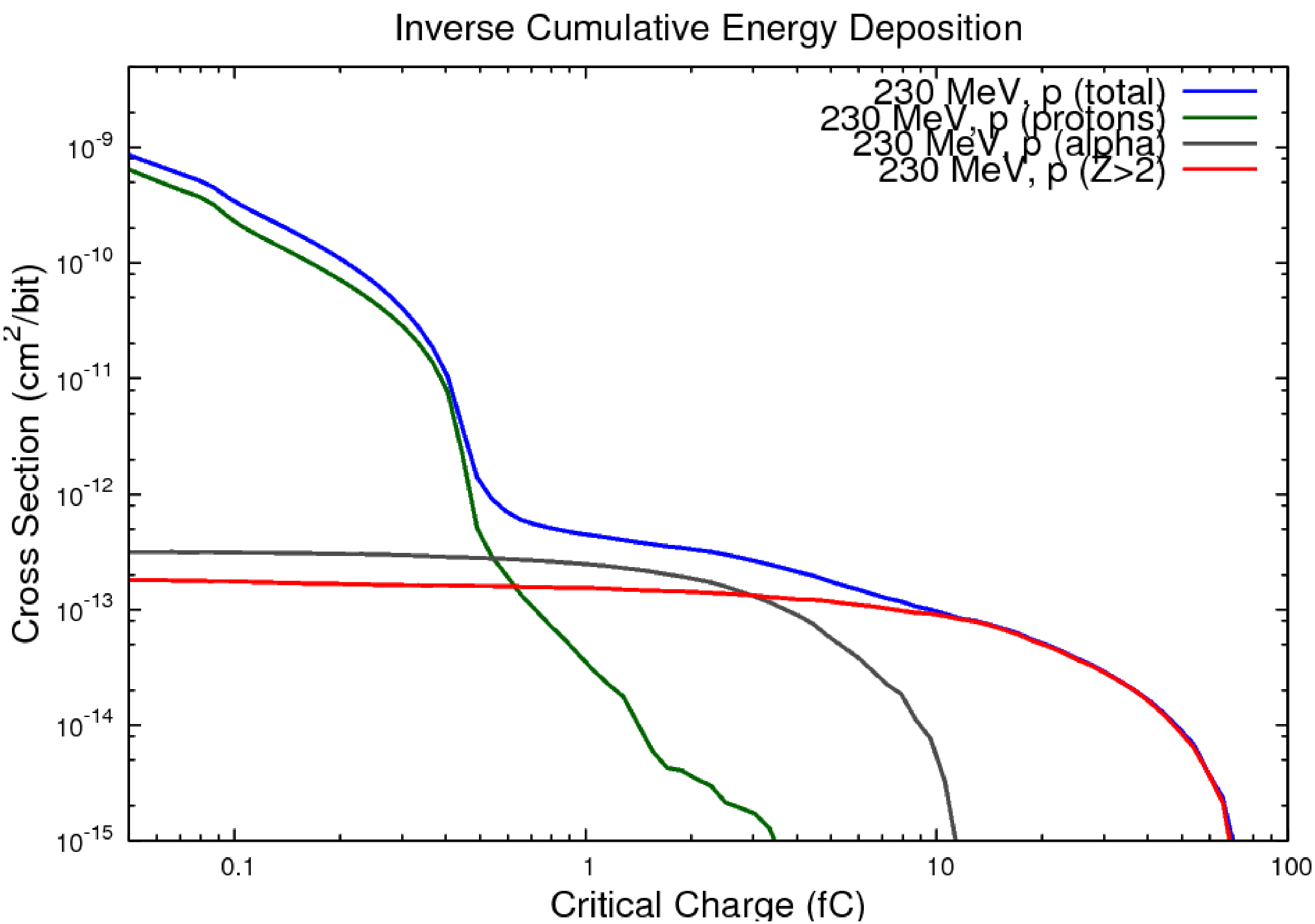
- 100 SV ($0.25\ \mu m^3$ each) in order to consider the sides effects while maintaining a good statistics/CPU time compromise.
- 6.7 μm BEOL of SiO_2 and Al.
- 380 μm Kovar lid with Au and Ni plating, included either explicitly in the transport simulation or in a two-step simulation (only considering the modification of the primary beam, no secondaries).

Energy deposition output

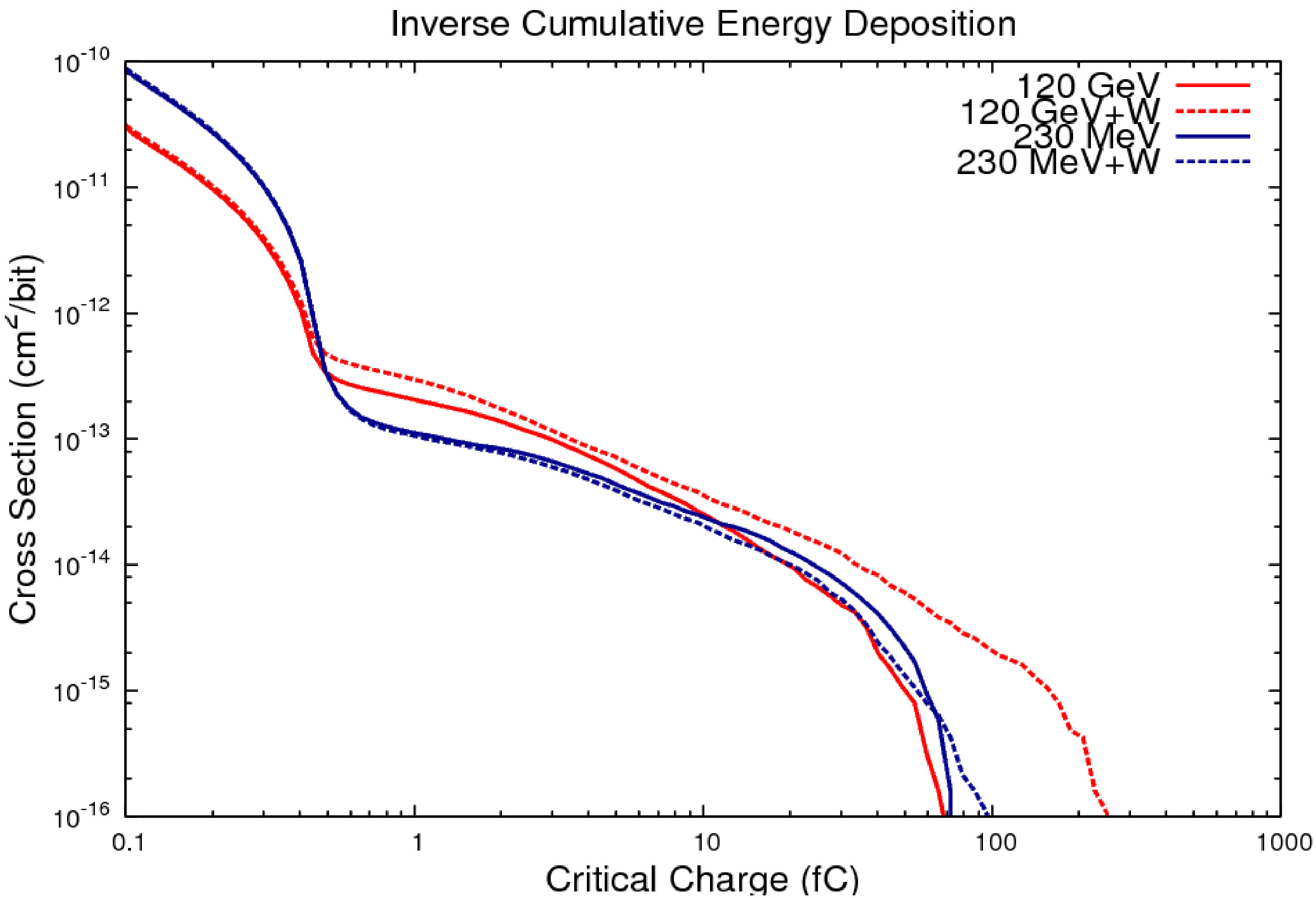


- direct/indirect energy deposition
- lid effect and dependence with E_{dep}
- physical surface of the device when Q_{crit} tends to zero

Energy deposition per particle type



Effect of 1µm tungsten layer (2µm from the SV)



Further work performed using the energy deposition routine

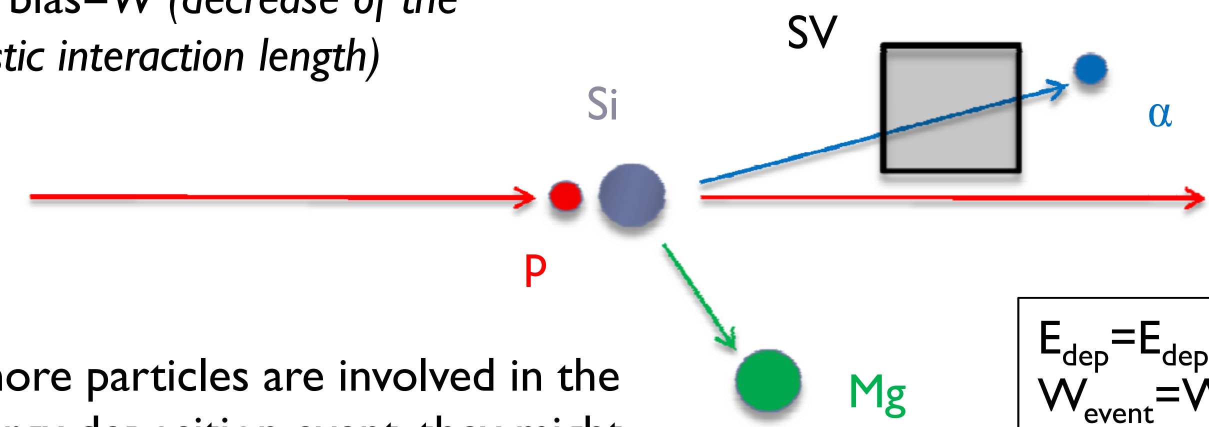
- Best fit of the critical charge of the RPP model to PSI experimental data for the ESA SEU monitor
- Use of the model to simulate the SEU cross section of particles and energy ranges not available for testing at standard facilities (charged pions, GeV energies)
- Benchmark of the resulting cross sections with the experimental SEU rate in an accelerator like mixed-field environment
- Benchmark of several GeV energy cross sections with the experimental monoenergetic values tested for at CERN
- Part of this work will be presented in the RADECS 2012 conference

Possible further development of the energy deposition tool

- Further breakdown of the contributions according to:
  - ionizing particle responsible for the energy deposition (by A and Z and not just FLUKA generalized particle)
  - origin of ionizing particle (primary, elastic, inelastic, spallation, fragmentation, evaporation, fission)
- Biasing of the inelastic events
  - very important especially for situation in which only very rare events can lead to an upset
  - if interested in the effect of long-ranged secondaries (alphas or singly charged particles) generated in the lid or the BEOL, the enhancement of the inelastic cross section is essential in order to compensate for the CPU time lost in transporting the charged (and therefore continuously slowing down) primary particles through the materials surrounding the SV.

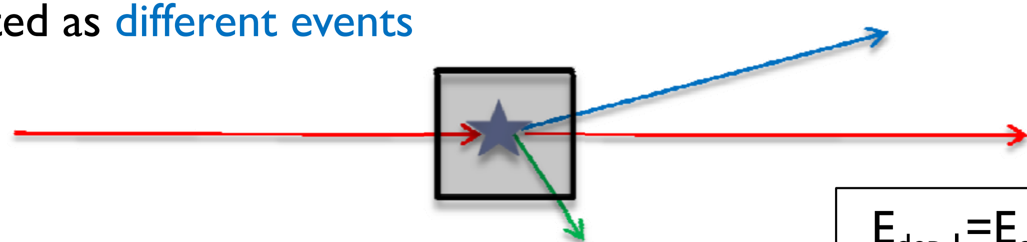
Possible implementation of biasing

LAM bias=W *(decrease of the inelastic interaction length)*



$E_{dep} = E_{dep,\ alpha}$
$W_{event} = W$

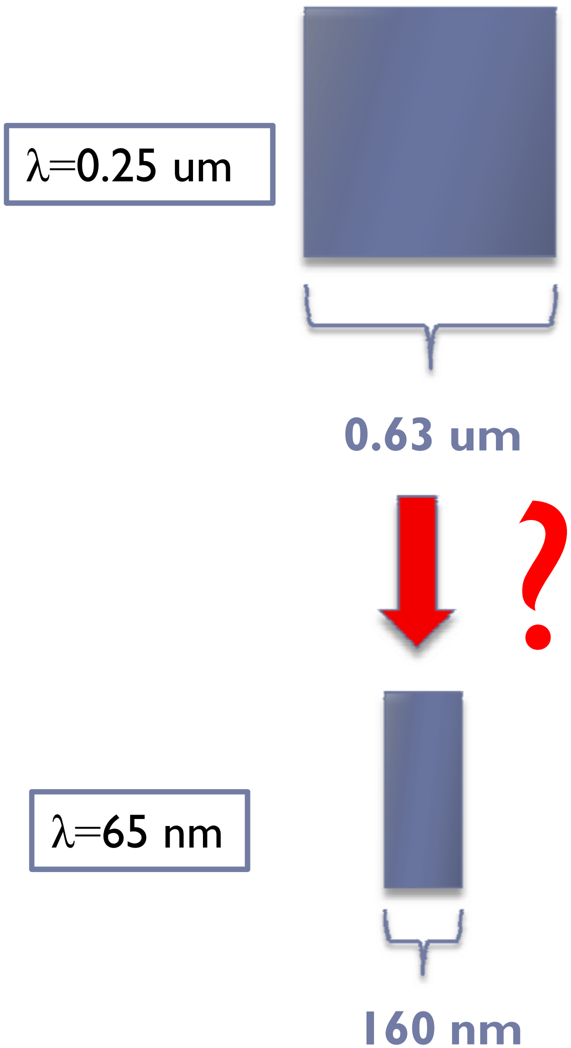
- if more particles are involved in the energy deposition event, they might belong to different outcome possibilities, and thus need to be treated as different events



particle generation tag might be useful for this purpose…

$E_{dep,1} = E_{dep,p1} + E_{dep,\ alpha} + E_{dep,\ Mg}$
$W_{event} = W$
$E_{dep,2} = E_{dep,p1} + E_{dep,\ p2}$
$W_{event} = 1\text{-}W$

Possible SV dimension limitations for modern SRAMs



- For a 0.25 um technology, a 0.25 um^3 collection volume is assumed.
- For more modern technology nodes (λ=65 nm, for instance) typical RPP SV values would need to be looked up in the literature, however one can in fist approximation assume $V \sim \lambda^3$ or $V \sim \lambda^2$.
- MC simulation limitations might arise for such small dimensions (molecular effects, etc.)
- Identifying and quantifying them would be important.

- Many thanks for you attention!
- Please feel free to pose questions, provide comments, etc.