Some special EM physics topics:

I. Using secondary production thresholds ("cuts")

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- Some special EM physics modelling topic to be discussed:
  - I. using secondary production thresholds (today)
  - II. the corresponding stepping and its parameters (next week)
  - III. multiple Coulomb scattering (in two weeks)

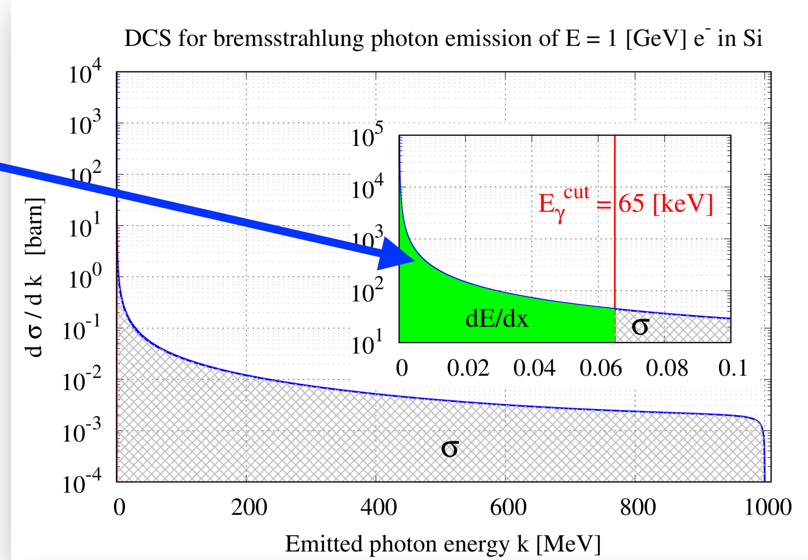
- There are some ongoing optimisations in which these might help
- We also have some pending issues (regarding the “cuts”, MSC)
- After some discussions with Marilena, it seemed to be a good idea to start working on these together by arranging these meetings
- These informal discussions might also help to tighten our collaboration

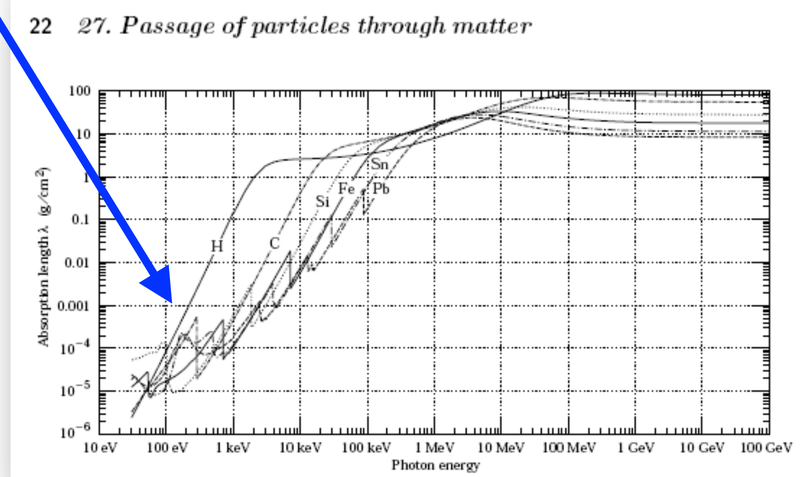
- I. using secondary production thresholds (today)
  - Do we need to use them? Why?
  - How dose it affect the stepping and performance?
  - What determines their appropriate values?
  - What are the consequences of using inappropriate values?
  - Secondary production thresholds in Geant4: some details.
  - How/when they are used beyond `ionisation` and `bremsstrahlung`? What are the differences in that case?
  - What we can learn form applying them in all possible interactions?

SECONDARY PRODUCTION THRESHOLDS

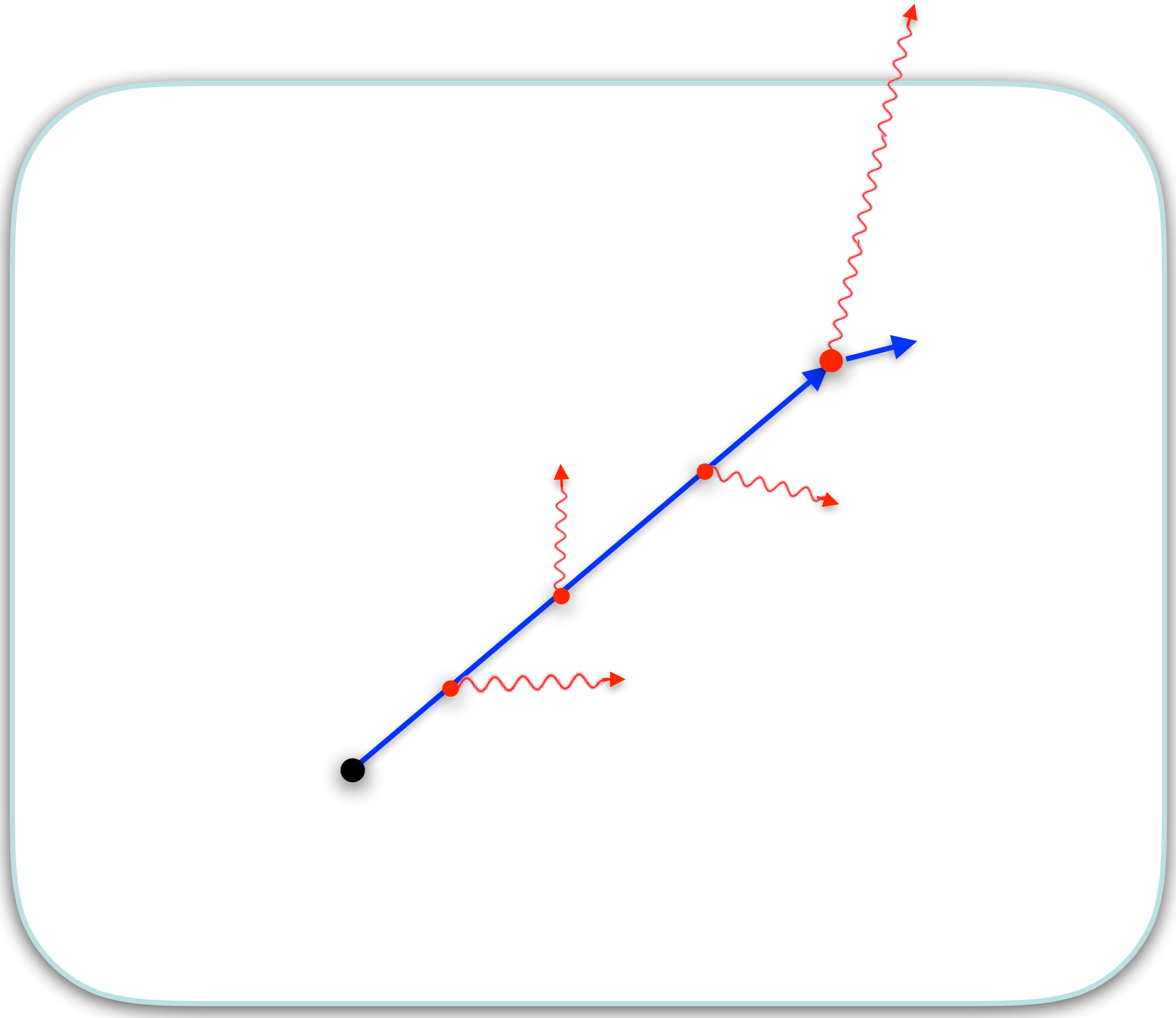
Secondary production threshold

- **Bremsstrahlung photon emission**:
  - low **energy** photons (k small) will be emitted with high rate i.e. DCS ~ 1/k
  - generation and tracking of all these low energy photons would not be feasible (CPU time)
  - but low energy photons has a very small absorption **length** (don't go far)
  - so if the detector spacial resolution is worst than this length (i.e. all volume boundaries are further), then the followings are *equivalent*:
    - ***a***: **generating and tracking these low energy photons till they (the corresponding energy) will be absorbed**
    - ***b***: **or just depositing the corresponding energy at the creation point (i.e. at a trajectory point)**
  - note, that we think in **energy** scale at the model level that translates to **length**(spacial) at the transport level
  - a secondary production threshold might be introduced (either in **energy** or **length)**
    - there is a clear translation from one to the other

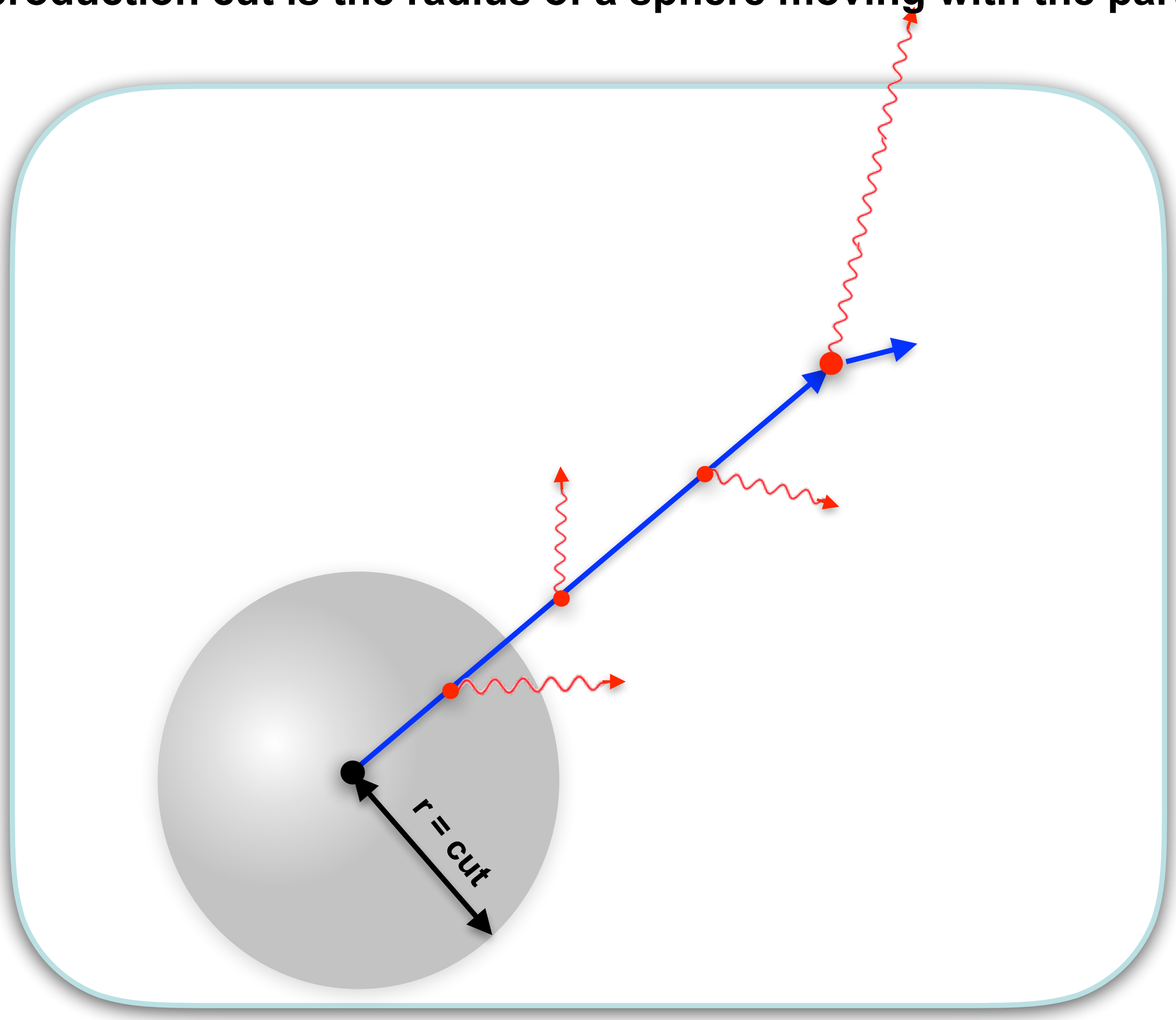




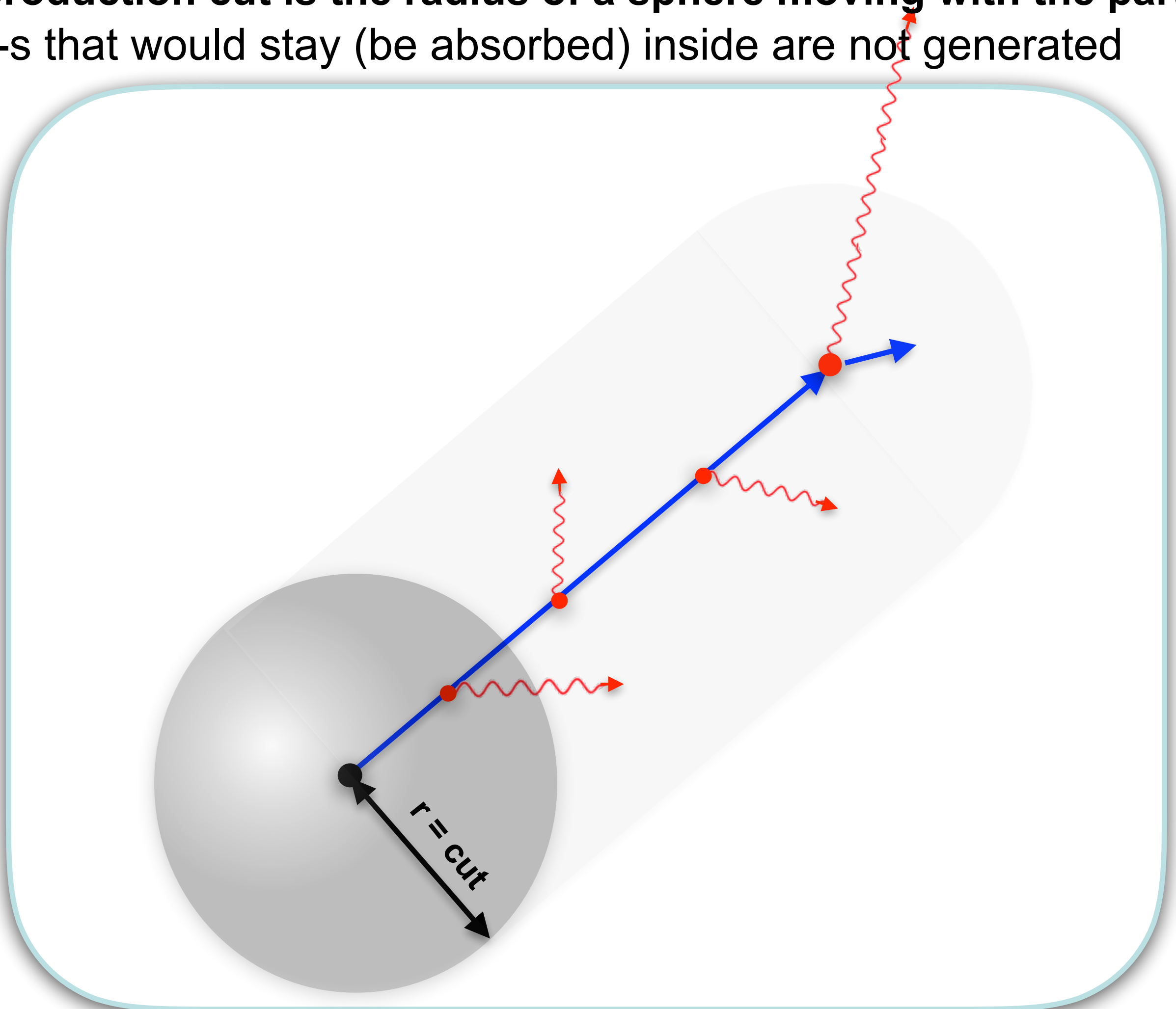
Secondary production threshold



Secondary production cut is the radius of a sphere moving with the particle:



Secondary production cut is the radius of a sphere moving with the particle (tube)**:**
secondary **γ**-s that would stay (be absorbed) inside are not generated



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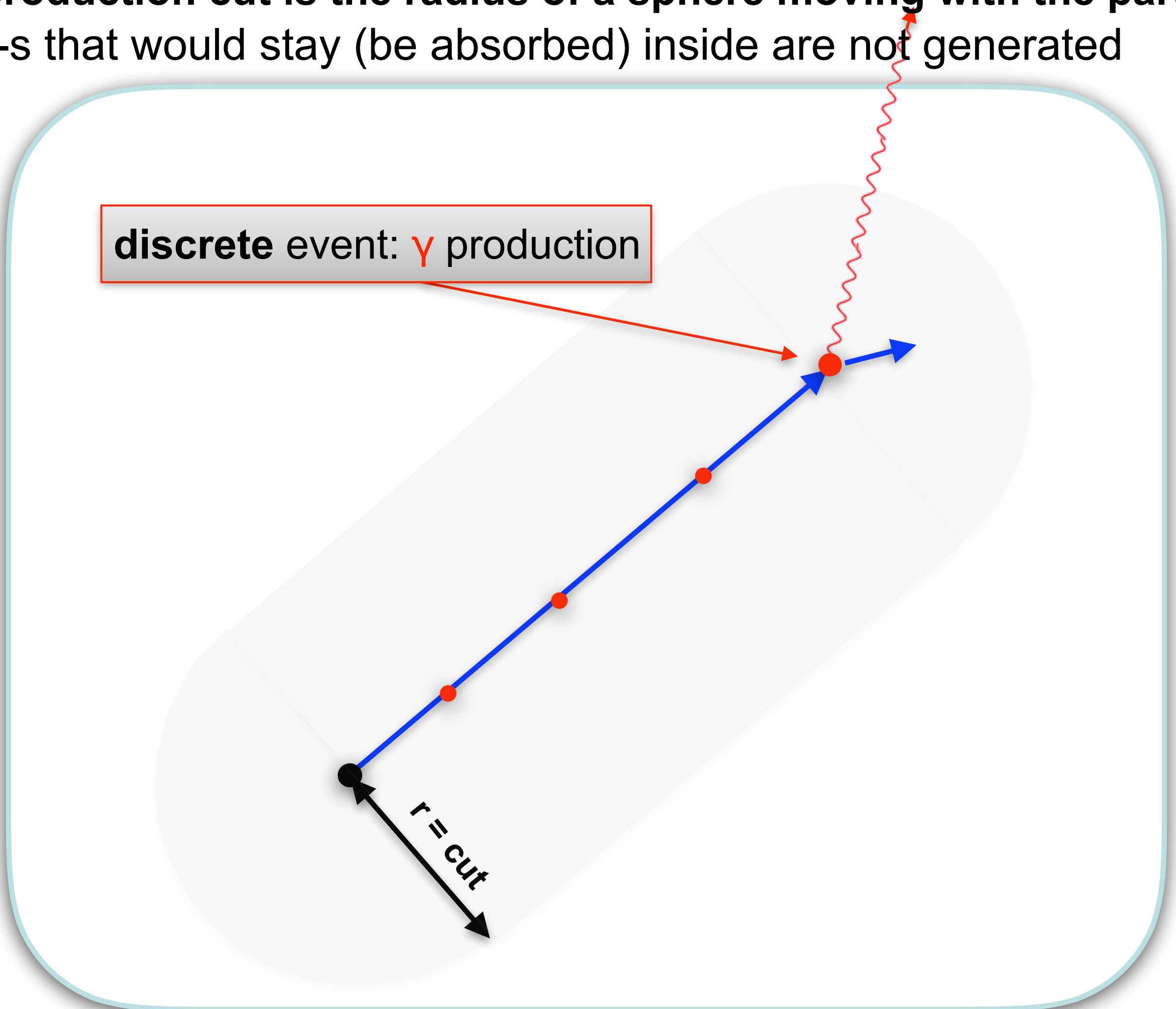

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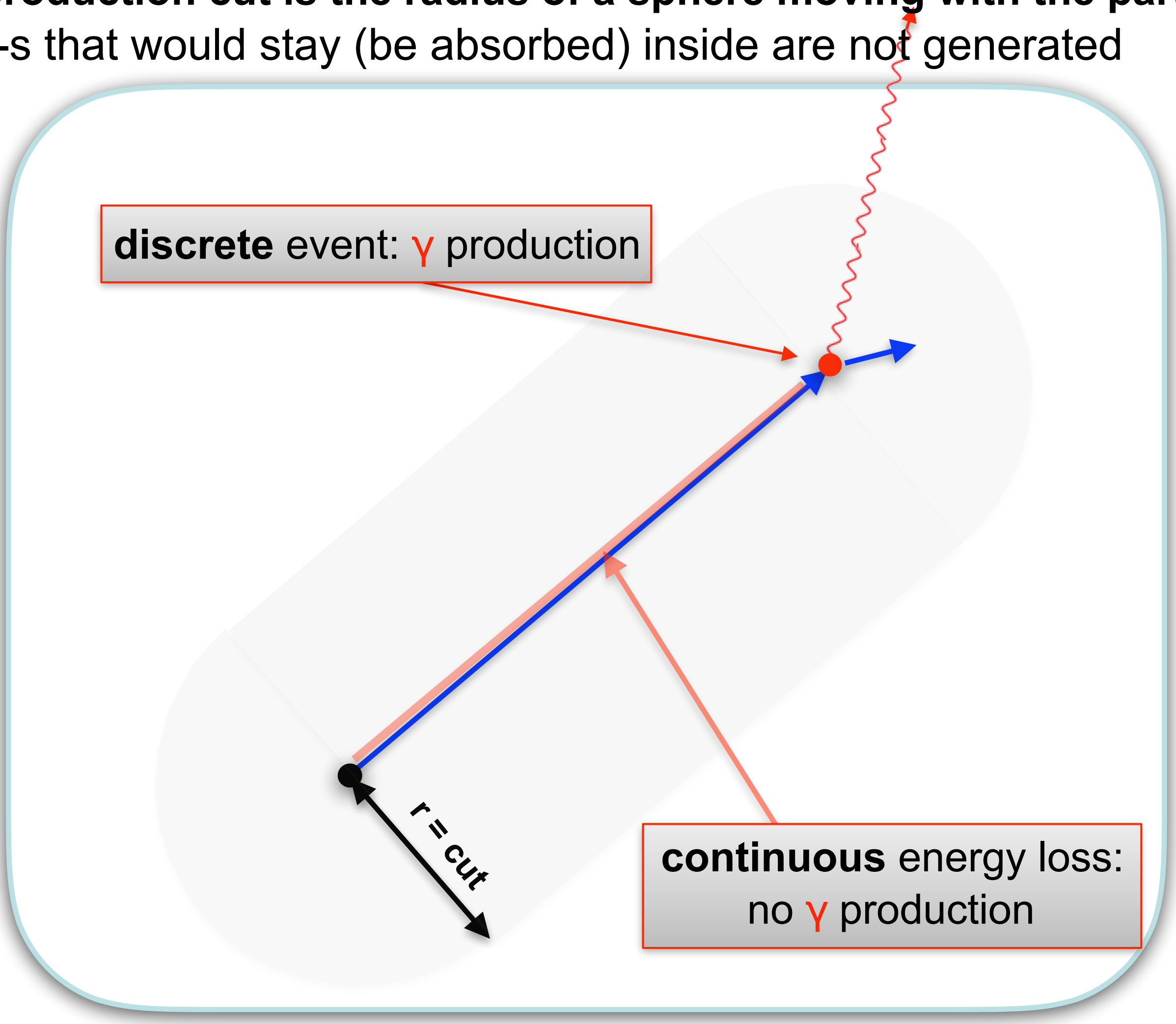
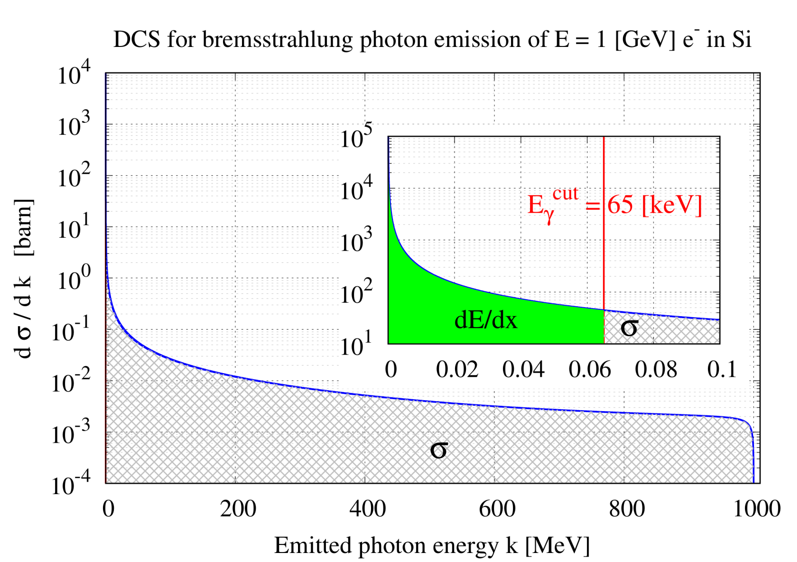


- **Introduce secondary photon production threshold**:
  - ***secondary photons***, **with** initial **energy below** a gamma production **threshold**(**k<E_γ^{cut}**), are **not generated**
  - ***E_γ^{cut}*** *is the **energy of the photon** that has **its absorption length equal to the cut** (**r**, i.e. the radius of the sphere)*
  - the corresponding **energy** (*that would have been taken away from the primary, but remained inside the sphere*) is **accounted as *CONTINUOUS* energy loss of the primary** particle **along its trajectory**
  - described by the **radiative** contribution of the (**restricted**) **stopping power** (**dE/dx**): mean energy loss due to sub-threshold photon emissions in unit (path) length
  - i.e. when an electron makes a step with a given length ***L***, one can compute the **mean energy loss** (due to sub-threshold photon emissions) along the step as ***L*** x ***dE/dx*** (would be true only if *E* = *const* along the step)
  - ***secondary photons***, **with** initial **energy above** a gamma production **threshold**(**k>E_γ^{cut}**), are **generated** (*since this energy is deposited outside of the sphere*) (***DISCRETE***)
  - the emission rate is determined by the corresponding (**restricted**) cross section(**σ**)



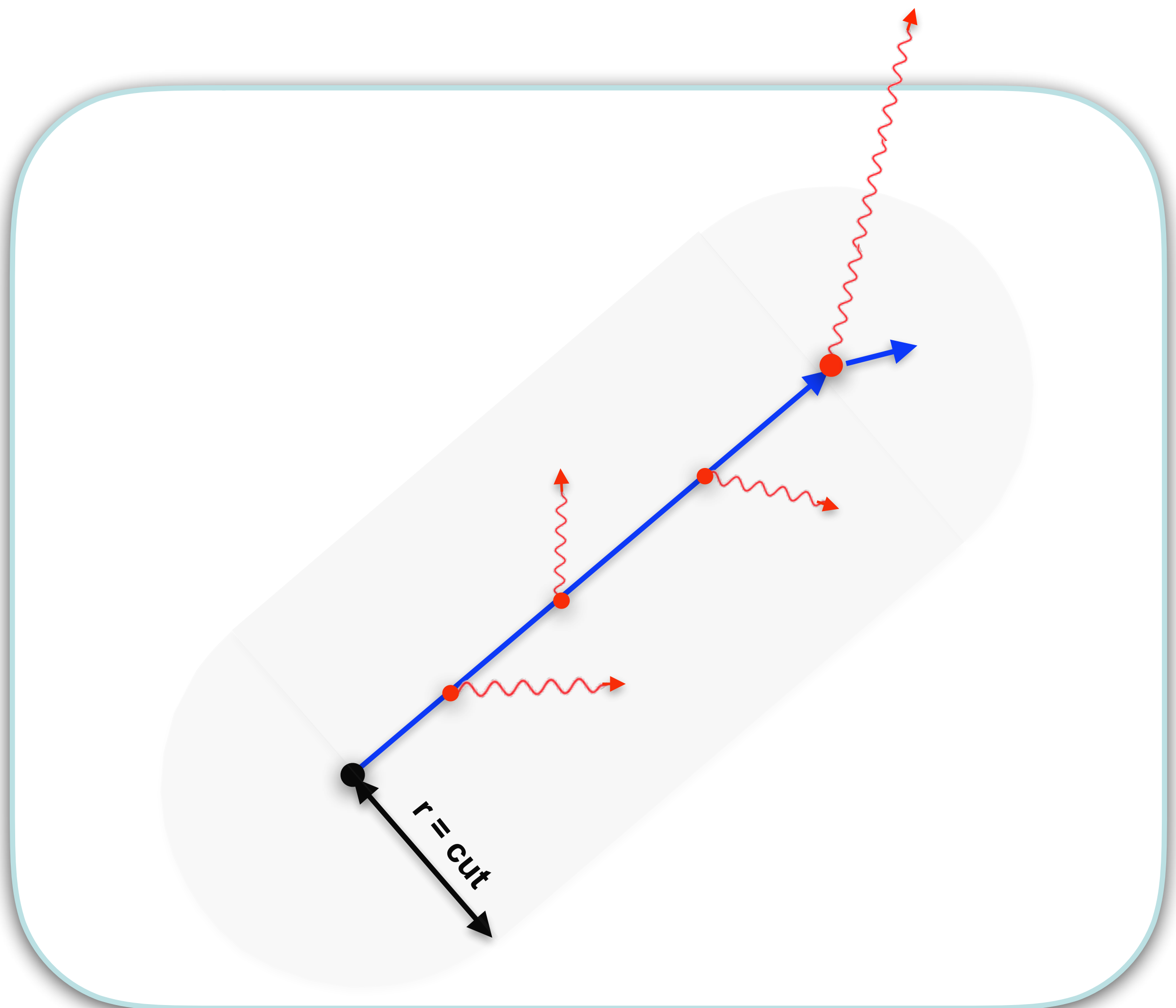
$$\frac{\mathrm{d}E}{\mathrm{d}x}(E, E_\gamma^{\mathrm{cut}}, Z) = \mathcal{N} \int_0^{E_\gamma^{\mathrm{cut}}} k \frac{\mathrm{d}\sigma}{\mathrm{d}k}(E, Z) \mathrm{d}k$$

$$\sigma(E, E_\gamma^{\mathrm{cut}}, Z) = \int_{E_\gamma^{\mathrm{cut}}}^{E} \frac{\mathrm{d}\sigma}{\mathrm{d}k}(E, Z) \mathrm{d}k$$

- **Same applies to ionization with the difference**:

- secondary gamma → secondary e^- production threshold
- absorption length → range
- ***$E_{e^-}^{cut}$*** *is the* ***energy of the electron*** *that has* ***its range equal to the cut*** *(**r**, i.e. the radius of the sphere)*

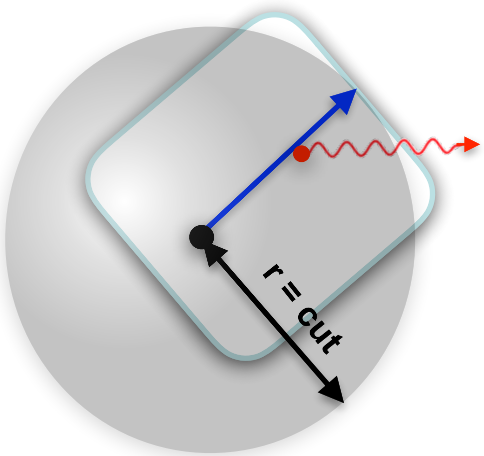
Secondary production threshold



Secondary production threshold << volume size : correct!

Secondary production threshold > volume size : not correct!

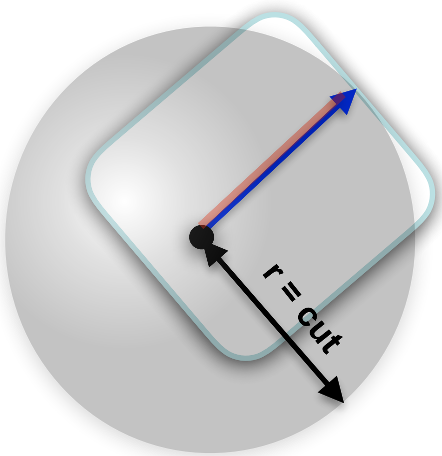
Secondaries, that would leave the volume, taking away their energy (or part of it in case of secondary e^-)**, are assumed to be absorbed within the volume!**



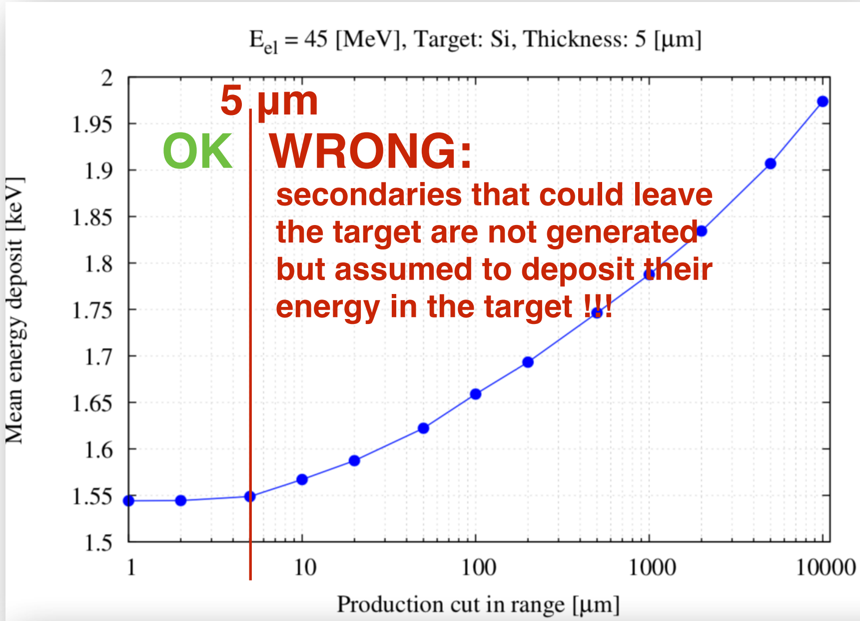
Secondary production threshold > volume size : not correct!

Secondaries, that would leave the volume, taking away their energy (or part of it in case of secondary e^-)**, are assumed to be absorbed within the volume!**

Wrong Energy Deposit: overestimated (in the volume)

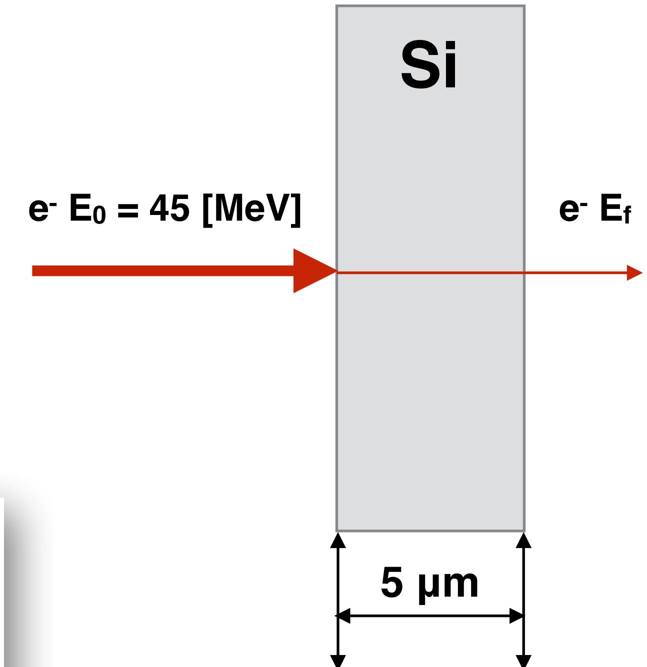


EXAMPLE



cut [µm]	mean E_{dep}	rms E_{dep}	prod. thres. [keV]		mean num. sec.	
			γ	e^-	γ	e^-
1	1.54423	0.000573911	0.99	0.99	0.0006811	0.1018230
2	1.54443	0.000583879	0.99	2.9547	0.0006843	0.0316897
5	1.54882	0.000605834	0.99	13.1884	0.0006857	0.0068261
10	1.56717	0.000665733	0.99	31.9516	0.0006730	0.0028232
20	1.58734	0.000743473	1.08038	47.8191	0.0006651	0.0018811
50	1.62223	0.000912408	1.67216	80.7687	0.0006557	0.0011304
100	1.65893	0.001108240	2.32425	121.694	0.0006518	0.0007536
200	1.69338	0.001342180	3.2198	187.091	0.0006465	0.000477
500	1.74642	0.001774670	5.00023	337.972	0.0006184	0.0002617
1000	1.78751	0.002219870	6.95018	548.291	0.0006054	0.0001622
2000	1.83440	0.002861020	9.66055	926.09	0.0005786	9.3e-05
5000	1.90700	0.004243030	14.9521	2074.3	0.0005427	4.07e-05
10000	1.97378	0.006036600	20.6438	4007.59	0.000521	2.22e-05

Compute the mean of the energy deposit in the target: E_0 - primary, E_f - final energy



SECONDARY PRODUCTION THRESHOLDS IN GEANT4

- **Secondary production thresholds in Geant4**:
  - user needs to provide them **in length** (with a **default value** of **1.0 [mm]; 0.7 [mm]** for the reference physics lists)
  - its proper value **application dependent** (as we saw, size of the sensitive volume, CPU)
  - the user needs to provide the proper value(s) in the `PhysicsList::SetCuts()` method
    - ✦UI command: `/run/setCut 0.1 mm` or `/run/setCutForAGivenParticle e- 0.1 mm`
  - (*range* and *absorption*) **length is** internally **translated to energies** at initialisation (mat. dep.)
  - the corresponding **energy** has a **minimum value**: **default 990 [eV]** but the user can set it
    - ✦UI command: `/cuts/setLowEdge 500 eV`
  - production threshold **defined for gamma**, **e$^-$**, **e$^+$** and **proton secondary particle** types
    - ✦**gamma** production threshold is used in **bremsstrahlung** while the **e$^-$** in **ionisation**
    - ✦e$^+$ production threshold might be used in case of e-/e+ pair production
    - ✦**proton** production threshold is used as a kinetic energy threshold **for nuclear recoil** in case of **elastic scattering** of ***all hadrons and ions***
    - ✦gamma and e$^-$ production thresholds might be used (optionally: `/process/em/applyCuts true`) in all discrete interactions producing such secondaries e.g. Compton, Photoelectric, etc.
  - it's not mandatory to use production thresholds(Condensed History; depends on the model)
  - however, high energy physics simulation would not be feasible without them !!!

- **Secondary production thresholds per detector region**:
  - different parts of a complex detector might require modelling with different level of details and have **different spacial resolution**
  - different **detector** `G4Region`-s can be defined and a set of `G4LogicalVolume`-s can be associated to such regions
  - **different** secondary **production threshold** values (as well as `G4UserLimits`) **can be assigned to different detector region**
  - very important fine tuning of the simulation settings for the given application:
    - ✦ how **frequently** the an electron **stops** and **number of secondary e^-/γ** particles strongly **depends on the secondary production threshold**
    - ✦ the **appropriate values are determined solely by the volume sizes** (spacial resolution)
    - ✦ applying the **proper values** is an important optimisation that do not later the results
    - ✦ identify regions of the detector with similar spacial resolutions (volume sizes), define the corresponding detector regions with the appropriate values (depending on the volume size) of secondary production threshold

- **Secondary production cuts vs tracking cut**:
  - Geant4 do not require any tracking cuts: e^--s are "ranged-out", photons absorbed
  - "ranged-out": appropriate final positions (see more on this next week)
  - however, the user can easily introduce any limits on tracking by `G4UserLimits`
  - a kinetic energy limit has been introduced recently:
    - ✦only for computing performance reasons: to kill low energy "loopers"
    - ✦this kinetic energy limit can be set to any (even to zero) energy values
    - ✦different values for e^-,e^+ and for hadrons, muons
    - ✦UI commands:

```
/process/em/lowestElectronEnergy 100 eV
/process/em/lowestMuHadEnergy 10 keV
```

  - particles are killed when their kinetic energy drops below the limit and their energy is deposited (at the given point!)
  - what this value should be?

- **Tracking cut on electrons:**
  - Why not: having a tracking cut that is the same as the secondary e^- production threshold? (energy? length? i.e. range?)
  - users can optimally have all or part of these, even per region, by using `G4UserLimits`
  - the main difference is that `G4UserLimits` are checked at the step limit, i.e. pre-step point (as a special user process) while the above, global tracking cut is already utilised within the step (whenever the e^- kinetic energy drops below the given limit)
  - nevertheless, the **most important not to generate particles with initial energy below a given secondary production threshold** (then these tracking cut has less importance)

CUTS BEYOND IONISATION AND BREMSSTRAHLUNG

Secondary production threshold: beyond `ionisation` and `bremsstrahlung`

- Using **condensed history description of `ionisation`** and **`bremsstrahlung`**
  - has very **strong influence** already **at the model level**, **determining** also several characteristics of **the whole simulation** (continuous-discrete process, fluctuation)
  - the **value of the secondary production threshold** will have a **strong influence** to the (restricted) **macroscopic cross sections**, that determine **the mean step length between** the corresponding discrete events leading to **secondary e^-/γ production**
- **This is not the case when** secondary e^-/γ **production threshold is applied to other processes:** **`/process/em/applyCuts true`**
  - the secondary **production threshold has no influence to the** corresponding **models** at all
  - there is **no any influence to the** corresponding macroscopic cross sections, i.e. to the **mean step lengths between successive interactions**
  - **neither to the production of** the **secondary** e^-/γ particles **at the model level**: ***always produced*** and ***the energy of the primary is always reduced accordingly***
  - however, **these sub-threshold secondary** e^-/γ **particles** are **not pushed to the** track **stack** at the higher `G4SteppingManager` or `G4VEmProcess`(discrete EM, e.g. gamma interactions) level
  - <u>this should not alter the results</u>:
    - ✦ altering the results is a clear indication of wrong, i.e. too high production threshold values
    - ✦ while otherwise the production threshold values are correct, might eve be too conservative (setting higher values might offer some possible performance benefits)
  - there is a misconception that it alters the results, especially the resolution due to the missing contribution to the fluctuation: but this is only due to forgetting the differences compared to the ioni./brem. cases.

- Using **condensed history description of `ionisation`** and **`bremsstrahlung`**
  - **sub-threshold** e-/γ **secondaries are not generated**, the primary do not even stopped to do so
  - the **corresponding** sub-threshold **energy loss**es are **accounted** as continuous energy losses of the primary along its steps
  - the **mean** value of these **energy losses along a** given **step** can be **computed by using the** corresponding (**restricted**) **stopping power**: **mean energy loss due to sub-threshold secondary** e-/γ **production** in ionisation/bremsstrahlung **in unit path length**
  - having the length of a given step, the mean energy loss can be computed(using linear aprx.)
  - **energy loss fluctuation model,** for providing samples according to the real distribution around this mean energy loss, is required

- **This is not the case when** secondary e-/γ **production threshold is applied to other processes:** `/process/em/applyCuts true`
  - the secondary **production threshold has no influence to the** corresponding **models** at all
  - the **secondary** e-/γ particles **at the model level**: ***always produced*** and ***the energy of the primary is always reduced accordingly***
  - independently if the corresponding secondary particle is used or discarded, **the post-interaction primary has the appropriate energy distribution**

THAT'S IT FOR TODAY