

# Getting Back-Scattering Information in Cascade Shower Tracking

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## 1 Purpose

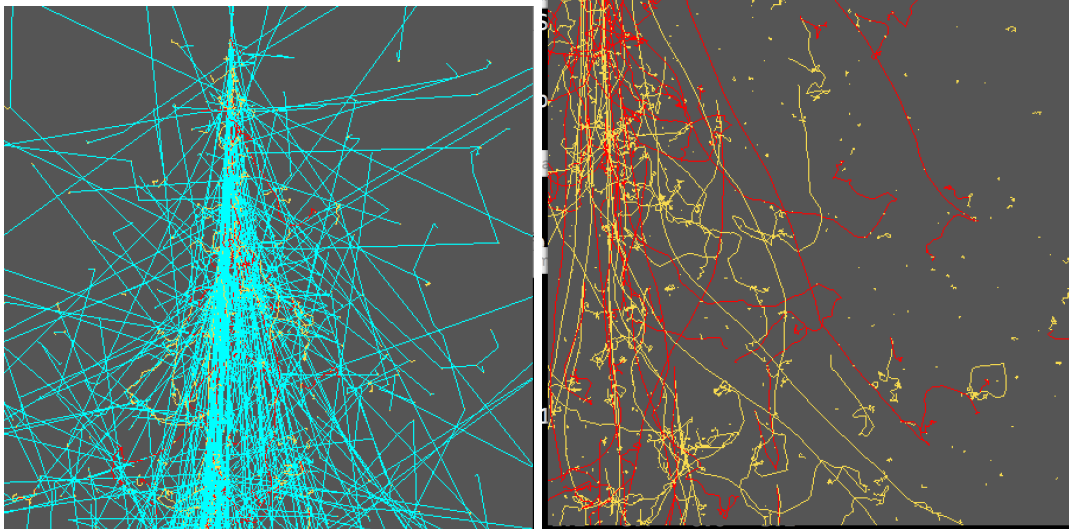


Figure 1: Trace image of a cascade induced by a 5 GeV  $e^-$  incident vertically in multi-layers of 0.35cm W. Left: Neutral particles (photons; cyan) are included. Right: Middle center part of the left fig. Photons are not shown: yellow is  $e^-$ , red  $e^+$ . Development is fairly complex. Low energy photons show Compton scattering and deflected largely but scattered electrons have low energies normally.

Suppose a cascade shower induced by an incident particle which is directed  $+z$  in a detector. Such a cascade normally develops forward ( $+z$ ) direction but some of particles go backward ( $-z$ ) direction. We describe here to get information of how much of energy deposit is due to such back-scattered particles and which process is most contributing to make such backward going particles.

## 2 Method

We use a user interface routine "epUI.f" which is called from EPICS whenever an interaction happens inside EPICS. For this, we prepare a file "epbacksc.f" which contains several subroutines to be called from "epUI" (or user-made its children). That means, the user must include such subroutine calls inside epUI (or its children) and inside ephook.f In some cases, the user needs to modify epbacksc.f but no need to touch EPICS source files.

## 2.1 Details

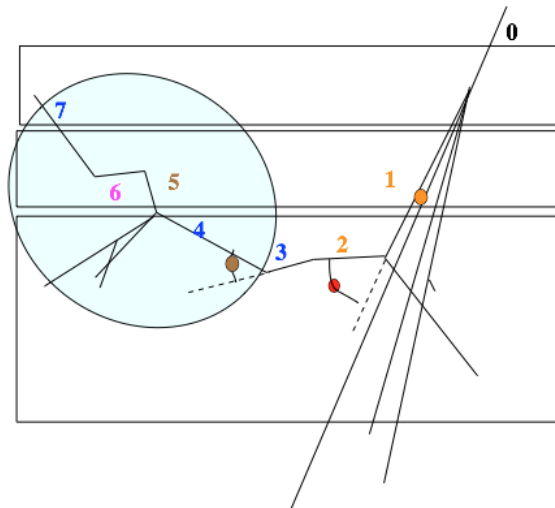


Figure 2: Direct ancestors of particle 7 are particle 6,5,..0. Among them, particle 4 is the first one which deflected to  $-z$  direction. Then, particle 4 and all its descendents (those in the circle including those going forward) are regarded as back scattered particles. The largest scattering angle among those of particle 4 and its direct ancestors is the one particle 2 suffered.

- Definition of back scattered particles:

When a particle direction cosine becomes negative first time, the particle there and all its descendents are regarded as back scattered particles, even though some of them might have changed the direction to  $+z$  (Fig.2). The user can change this definition.

- We record the largest scattering angle and its interaction type (Compton, Brems,...etc) of a particle before it is regarded as back scattered. “A particle” here means the particle itself and its direct ancestors (Fig.2). We don’t care that a particular scattering is pro or con the back scattering. How to define “the largest” can be changed by the user.
- When a particle puts energy deposit, we check whether it is back-scattered one. If so, besides normal energy deposit sum calculation, we take special sum with flag of interaction type mentioned above.
- The interaction types are classified into 6:1) Compton, 2) hadronic interaction (including decay), 3) brems, 4) knock-on (Møller or Bhabha scattering), 5) positron annihilation, and 6) others. This can be changed by the user. Currently, the multiple Coulomb scattering (MCS) is not included as an individual interaction, though its cumulative effect to the lateral spread is the largest.

## 2.2 Implementation of ebacksc.f

A template of ebacksc.f can be found in Epics/UserHook/backscat.

- Place ebacksc.f inside a folder where your application programs (ephook.f etc) are located.
- Make a 1 line file named BACKSC.h; it may contain

```
#define BACKSCAT  
or blank line or #undef BACKSCAT
```

The program must be constructed so that if “BACKSCAT” is defined here, the back scatter treatment should be active.

- Put a line  
`#include BACKSCAT.h`  
at the top of a program file which includes codes to treat the back scattering and compiled independently of other such files. Mandatory one is `ephook.f`  
If `epUI.f` is compiled without being included in `ephook.f`, it is another example.

- By “make”, `epbacksc.f` must be compiled. For that,
  - Modify `ephook.mk` so that the “objs” term reads like

```
objs =epbacksc.o ephook.o epos2B.o
```

in which `epbacksc.o` must be placed before `ephook.o`.

In this case, `epbacksc.f` is always compiled independently of “BACKSCAT”, but there will be no harmful effect. If the user modifies `epbacksc.f`, “make” will automatically re-compile it in this case.

- Alternatively, the user may change `ephook.f`: Insert liens:

```
#if defined (BACKSCAT)
#include "epbacksc.f"
#endif
```

somewhere in the top part of `ephook.f`. In this case, the user must “make clean“ before “make” if the user modifies `epbacksc.f`.  
Omitting `#if` and `#endif` lines is also OK as in the first case.

- Add a line in subroutine `uiaev`  
`call epbacksc0`  
for initialization of all events. It could be in a child of `uiaev`.

```
uiaev or its child
....
#if defined (BACKSCAT)
call epbacksc0
#endif
...
```

- For initialization of 1 event generation,

```
uafillev or its child
....
#if defined (BACKSCAT)
call epbacksc1
#endif
...
```

- For the energy deposit calculation,

```
userde or its child
...
cn2 = ...
#if defined (BACKSCAT)
call epbackscdE(cn2, aTrack, Move%dEeff).
#endif
... ordinary deposit sum calculations
```

If all of the components in a detector are target, `cn2` would be `aTrack%cn`. However, the user may want to select some of the components and map them to serial numbers starting from 1. `cn2` stands for such a number; the mapping scheme (`aTrack%cn` to `cn2`) must, of course, be

prepared by the user. (Note: The energy deposit in each of all components is automatically taken in EPICS.)

- To output the energy deposit calculation result, add some in `subroutine uelev` or its child. The energy deposit due to back scattered particles is available as `Elossbs(i,j)` via module `modbacksc` where  $i$  is the index corresponding to  $cn$  or  $cn2$  and  $j$  the index for interaction type associated with the largest scattering angle ( $j = 1 \sim \text{maxindex}$  (default is 6)). Thus, the structure will be

```

uelev or its child
subroutine uelev (or child)
#if defined (BACKSCAT)
use modbacksc
#endif
implicit none
...
#if defined (BACKSCAT)
write(...) ... Elossbs(cn2, :), ...
#endif
...

```

- Modify `epUI.f` or its child
  - To record the largest scattering angle and the interaction type responsible for such an angle, use `epUI` or its child. The argument, “info”, in `epUI` must be made to be 0 on return.

```

epUI or child
subroutine epUI (or its child)
...
#if defined(BACKSCAT)
call epbackscUI(info, loc1, loc2)
#endif
...

```

If the call is from the child, the 3 arguments to `epUI` must be inherited to the child.

### 2.3 Modifying `epbacksc.f`

- Inherit information from `ephook` or its child: normally the user include a file by, say, putting `#include Zzzz.h` which is used in the user’s `ephook` or its child routines so that some of variables in such a file must be commonly used: typically such places would be `epbacksc0` `epbackscdE`

In stead of including `Zzzz.h` to use common variables, the use may use an own module.

- Backward direction definition. The  $-z$  direction can be changed by giving different value to `backscdircos` in module `modbacksc`. It is direction cosine in the world coordinate. If a particle’s direction cosine becomes smaller than this value. it is regarded as back scattered. (default is 0.)
- The minimum kinetic energy of charged particles for which the largest scattering angle is recorded. Since low energy charged particles are easily deflected in large angles but stop soon, it would be not appropriate to check low energy charged particles for such a purpose.. The minimum kinetic energy can be changed via `EkchminForLargeAng`(default is  $1.d-2 = 10$  MeV)

- `EknminForLargeAng` is the same for neutral particles (mainly for photons). This is much smaller since photons can travel longer distance. (default is `50d-6= 50 keV`).
- Interaction type. The number of interaction types can be changed by `maxindx` (default is 6). Assignment of index (Compton is index 1, etc) may be changed in the subroutine `epbackscUI`. If the component number is large, and `maxindx` is large, we need a large memory space. Be careful.
- For each track, the largest scattering angle, the index of interaction type associated with that scattering and the flag for the back scattering (whether it or its descendants already have suffered back scattering) are stored in each track information `%user`. E.g, for a track, `aTrack`, `aTrack%user`. It is an 8 byte variable. Once it is copied to `user` in `modbacksc`, the user can use `cosOfLargestAngle` (the largest scattering angle), `procIndx` (index of the process), `bsflag` (the particle or its ancestors have been back scattered (-1) or not (0)).

### 3 Simple example

A simple example is contained in `Epics/UserHook/backscat`. The configuration there is simple. A  $100\text{ cm} \times 100\text{ cm} \times 0.35\text{ cm}$  thick plate is stacked repeatedly (in total 30 layers). An electron is injected vertically from the top of the 6th layer at the center. Therefore any energy deposit at layers 1 to 5 should be by back scattered particles.

#	dE(GeV)	Comp	Had	Brem	Knoc	anih	oth	BS_tot%
1	3.2122E-02	0.0	0.0	13.7	46.0	3.9	36.5	100.
2	4.5540E-02	0.9	0.0	38.5	26.8	5.2	28.6	100.
3	7.0055E-02	6.3	2.9	9.5	29.8	1.6	49.9	100.
4	0.1003	6.9	0.0	23.1	35.4	2.6	31.9	100.
5	0.1395	4.0	1.7	34.8	30.3	2.4	26.9	100.
6	0.2702	2.1	2.2	24.2	30.8	1.9	17.6	79.
7	1.078	2.4	0.3	18.8	19.6	0.5	17.1	59.
8	2.979	2.4	0.1	17.0	19.6	1.0	13.8	54.
9	6.578	3.0	0.1	16.3	16.8	0.4	15.1	52.
10	12.80	3.2	0.1	15.5	17.2	0.6	15.0	52.
11	21.16	3.9	0.4	16.1	19.6	0.7	12.5	53.
12	29.14	4.5	0.6	17.0	20.2	0.8	12.0	55.
13	35.33	5.4	0.1	17.6	20.8	0.9	11.9	57.
14	40.13	5.9	0.3	18.6	19.8	0.8	12.4	58.
...								
23	15.95	14.3	0.5	21.8	15.4	2.0	13.1	67.
24	13.12	15.0	0.4	22.4	14.2	1.7	14.4	68.
25	10.97	15.9	0.4	21.6	14.8	1.7	14.3	69.
26	8.356	18.7	0.3	21.7	14.0	2.0	13.1	70.
27	6.460	20.2	0.4	21.7	13.9	1.7	13.2	71.
28	5.134	21.1	0.4	22.4	13.4	2.2	12.2	72.
29	3.860	22.7	0.5	22.0	13.5	2.0	11.9	73.
30	2.655	26.4	0.0	20.2	10.5	3.5	10.4	71.

The example shows a 500 GeV electron case. First col. is layer number,, 2nd total energy deposit in that layer, 3rd to 8th col: Percentage of energy deposit by particles of which the largest scattering angle is due to the Compton, hadronic interaction, brems, knock-on, annihilation and others. The last col. is total contribution of back scattering in percentage. (sum of col. 3 to 8); as expected, the layers from 1 to 5 show 100 %.

One may note that Compton contribution is not large in spite of that large angle scattering of gamma rays are prominent in particle trace image. This is probably because Compton scattering takes place for low energy gamma rays, and ancestors of many of such gamma rays would have already been suffered a large angel scattering and already going backward.

Note for taking average of many events when the incident is proton etc. if the starting point is from the 6th layer, the energy deposit in layer 1 to 5 could be exactly 0 when proton interact at a deep layer. Depending of how to treat these 0 events, the average of total back scattering contribution for many events becomes less than 100 % even at layer 1 to 5.