CUSP
Geant4 checks

Sergio Fabiani

INAF-IAPS

Proposal for a format of data handling

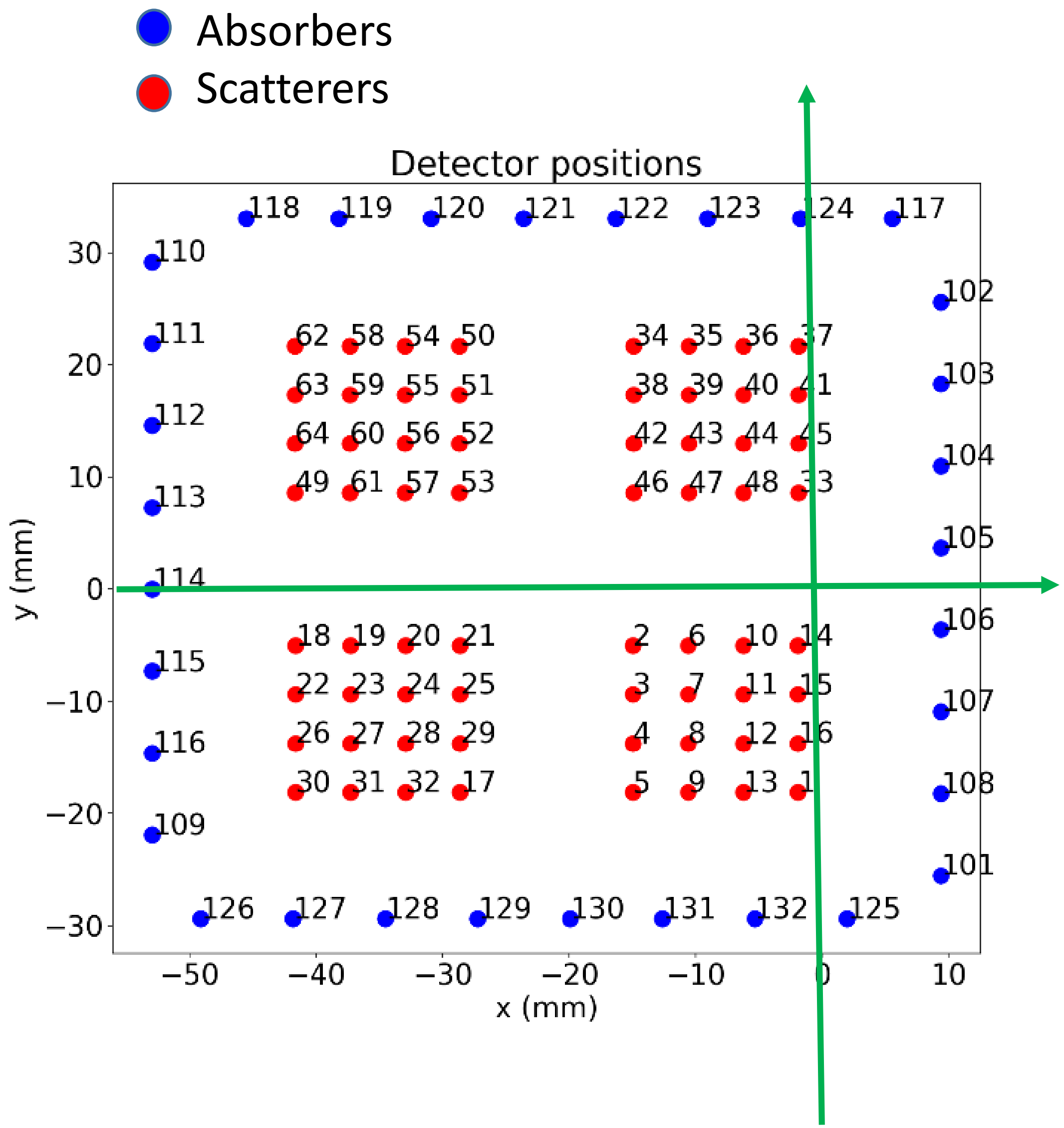
- Data organized in a python nested dictionaty as a Event list, not a Pandas DataFrame
- The first level is the «event ID», corresponding to a photon detected
- The event ID is repeated in the lower level for readability
- Other options can be discussed

```
#%%timeit

hdul = fits.open("scorefile.fits")
hdul.info()

events = hdul[1].data
print(events.columns)

t_ID = events['EventID']
t_ED = events['En_dep']
t_SI = events['Scint_ID']
t_XP = events['X_Primary']
t_YP = events['Y_Primary']
t_ZP = events['Z_Primary']
t_TP = events['Theta_Primary']
t_PP = events['Phi_Primary']
t_EP = events['En_Primary']
t_Dx = events['X_Detected']
t_Dy = events['Y_Detected']
t_Dz = events['Z_Detected']
```

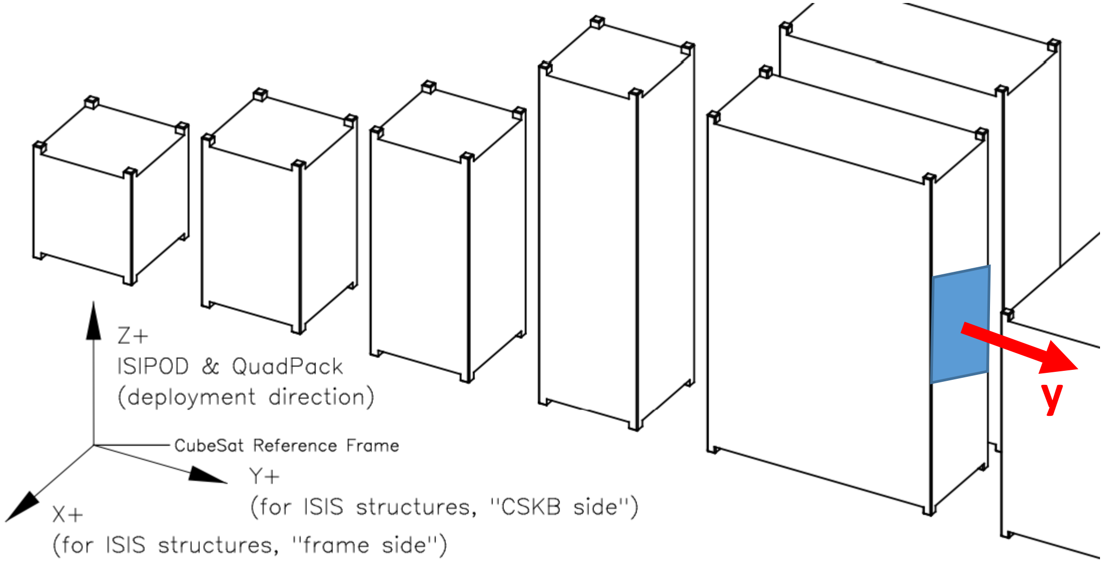
```
{'EventID': 3,
'En_dep': array([59.92782382]),
'Scint_ID': array([113]),
'X_Primary': array([-5.30081678]),
'Y_Primary': array([0.53783171]),
'Z_Primary': array([-8.]),
...}
```

```
#%%timeit

EventList={}
for evtID in t_ID:
    EventList[evtID]={}
    EventList[evtID]['EventID']=evtID
    EventList[evtID]['En_dep']=[]
    EventList[evtID]['Scint_ID']=[]
    EventList[evtID]['X_Primary']=[]
    EventList[evtID]['Y_Primary']=[]
    EventList[evtID]['Z_Primary']=[]
    EventList[evtID]['Theta_Primary']=[]
    EventList[evtID]['Phi_Primary']=[]
    EventList[evtID]['En_Primary']=[]
    EventList[evtID]['X_Detected']=[]
    EventList[evtID]['Y_Detected']=[]
    EventList[evtID]['Z_Detected']=[]

for i,evtID in enumerate(t_ID):
    EventList[evtID]['En_dep'].append(t_ED[i])
    EventList[evtID]['Scint_ID'].append(t_SI[i])
    EventList[evtID]['X_Primary'].append(t_XP[i])
    EventList[evtID]['Y_Primary'].append(t_YP[i])
    EventList[evtID]['Z_Primary'].append(t_ZP[i])
    EventList[evtID]['Theta_Primary'].append(t_TP[i])
    EventList[evtID]['Phi_Primary'].append(t_PP[i])
    EventList[evtID]['En_Primary'].append(t_EP[i])
    EventList[evtID]['X_Detected'].append(t_Dx[i])
    EventList[evtID]['Y_Detected'].append(t_Dy[i])
    EventList[evtID]['Z_Detected'].append(t_Dz[i])

for i,evtID in enumerate(t_ID):
    EventList[evtID]['En_dep']=np.array(EventList[evtID]['En_dep'])
    EventList[evtID]['Scint_ID']=np.array(EventList[evtID]['Scint_ID'])
    EventList[evtID]['X_Primary']=np.array(EventList[evtID]['X_Primary'])
    EventList[evtID]['Y_Primary']=np.array(EventList[evtID]['Y_Primary'])
    EventList[evtID]['Z_Primary']=np.array(EventList[evtID]['Z_Primary'])
    EventList[evtID]['Theta_Primary']=np.array(EventList[evtID]['Theta_Primary'])
    EventList[evtID]['Phi_Primary']=np.array(EventList[evtID]['Phi_Primary'])
    EventList[evtID]['En_Primary']=np.array(EventList[evtID]['En_Primary'])
    EventList[evtID]['X_Detected']=np.array(EventList[evtID]['X_Detected'])
    EventList[evtID]['Y_Detected']=np.array(EventList[evtID]['Y_Detected'])
    EventList[evtID]['Z_Detected']=np.array(EventList[evtID]['Z_Detected'])
```

Mass Model and System of Reference



- The mass model simulated is the current design, but:
  - the system of reference has the axes exchanged with respect to Req. CUSP-SAT-0029 and the origin is not in position (fixed in the next version of the mass model)
  - The collimator is not present, but it is not relevant for this analysis (fixed in the next model version)
  - The plastic bars are a fraction of mm shorter than the nominal length of 45mm. This is not relevant for this analysis (fixed in the next model version)

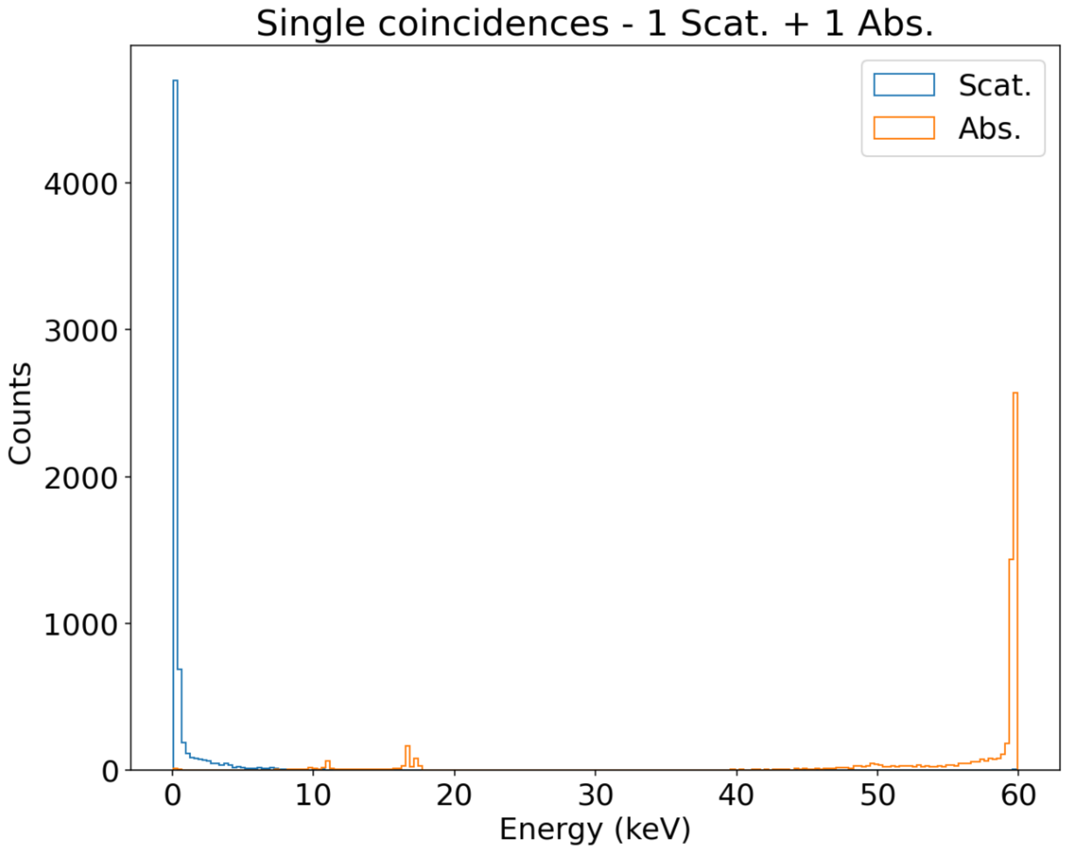


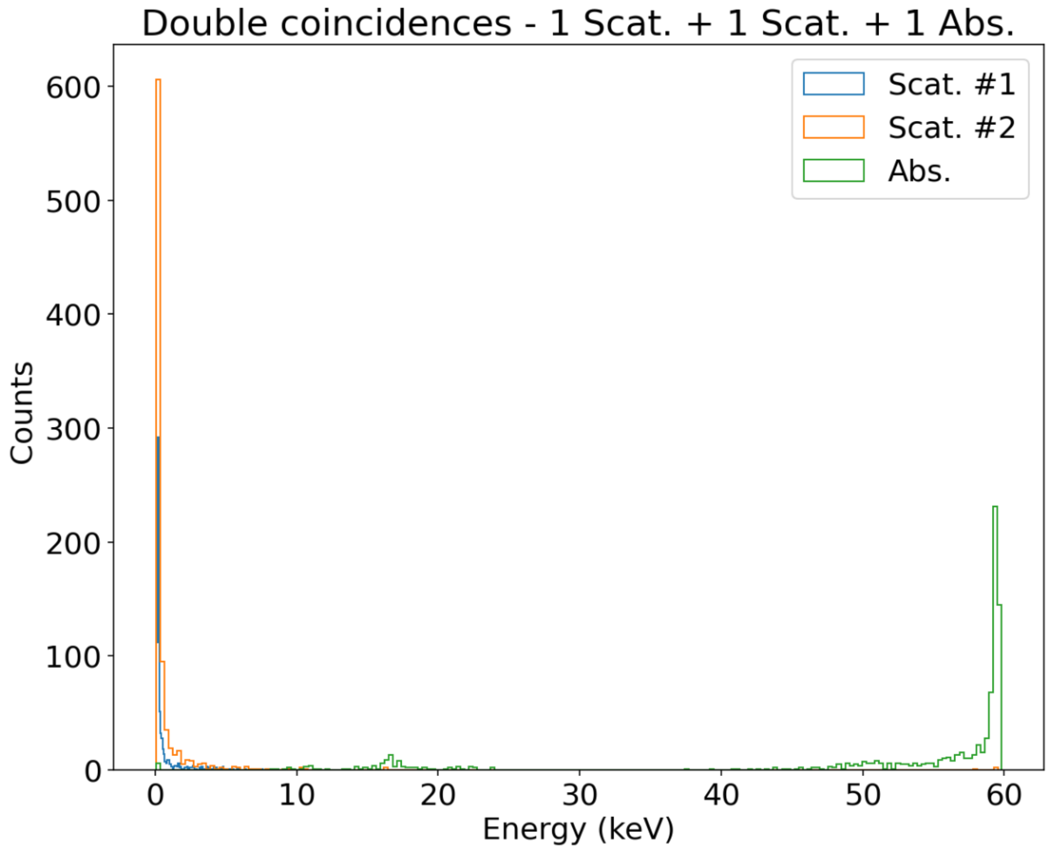
Simulation info

- Unpolarized (Giovanni DC, check needed) radiation at 60 keV, emitted from a flat squared source 8x8 cm^2 on the top of the detector
- 10^6 photons launched, 327 815 total events detected

Energy deposits of coincidences

- Double coincidences are about 12% of total coincidences
- Compton energy deposit in scatterers and photoelectric energy absorption in the absorber
- The Compton energy deposit in the scatterers (about 0.2 keV in average) is smaller than expected (there should be a significant fraction of 2-5 keV events)





Energy deposits of coincidences

- The Compton energy deposit in the scatterers (about 0.2 keV in average) is smaller than expected (there should be a significant fraction of 2-5 keV events)
- The 60 keV photons scattered at 15 deg deposit about 0.24 keV. Too much forward folded wrt energy?

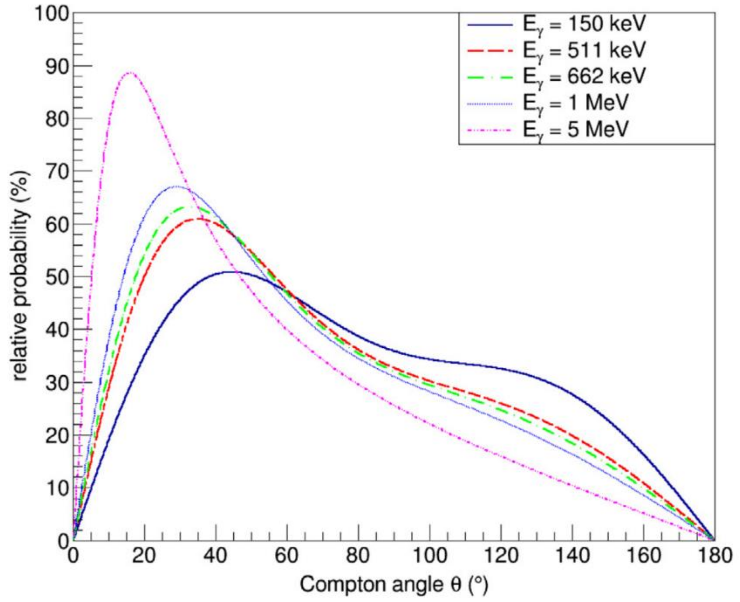
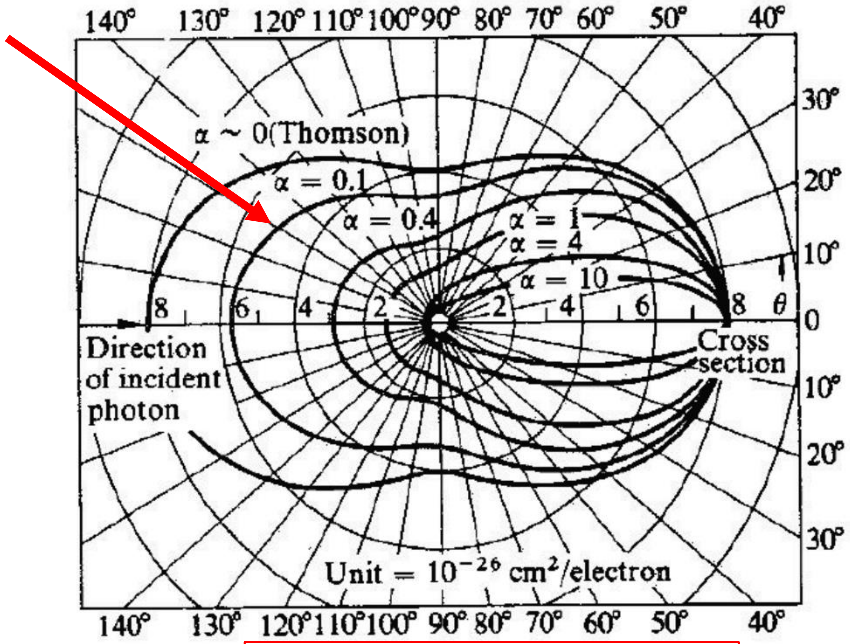
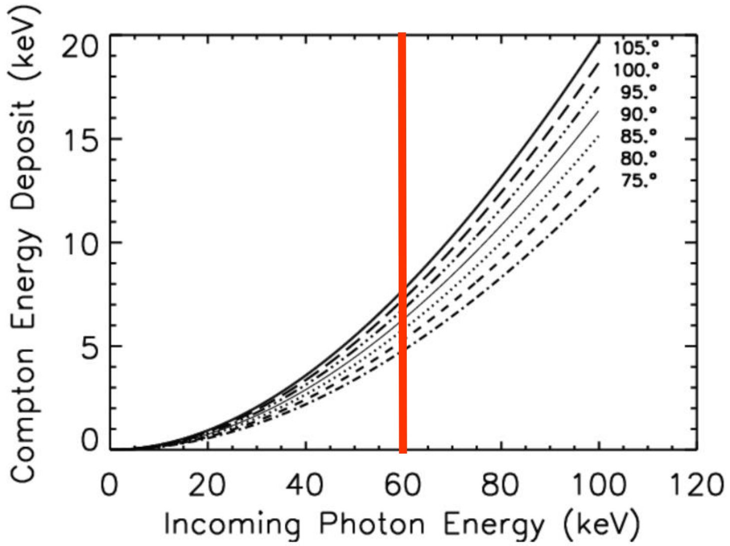


Fig. 2. Relative scattering probability as a function of the Compton angle for a series of γ-ray energies between 150 keV and 5 MeV.



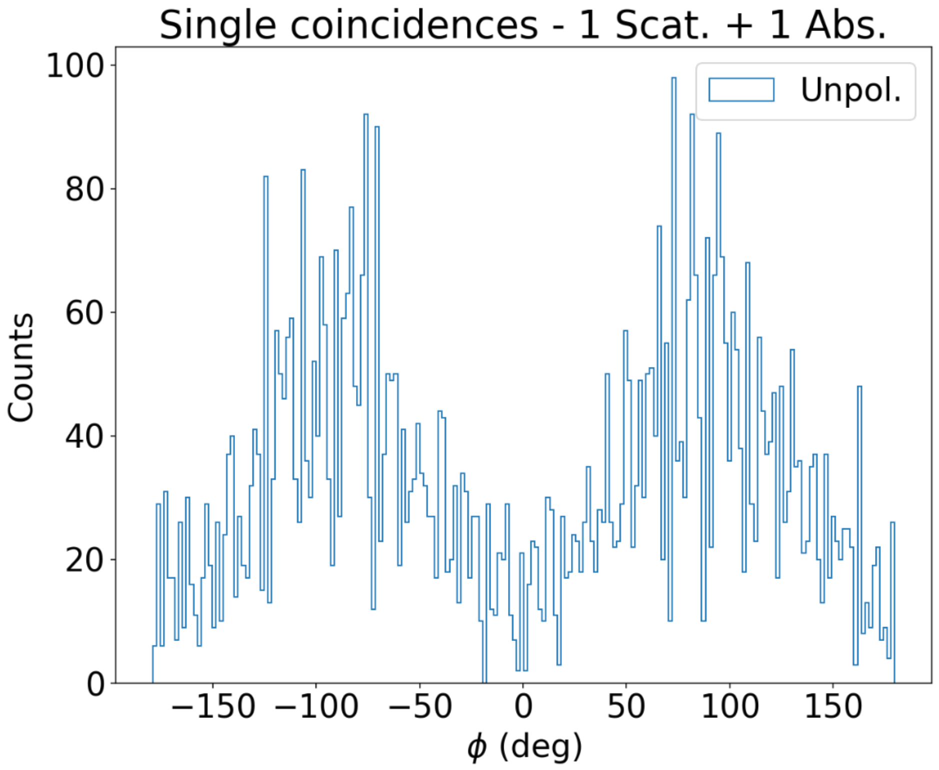
α = 60 keV/511 keV = 0.12

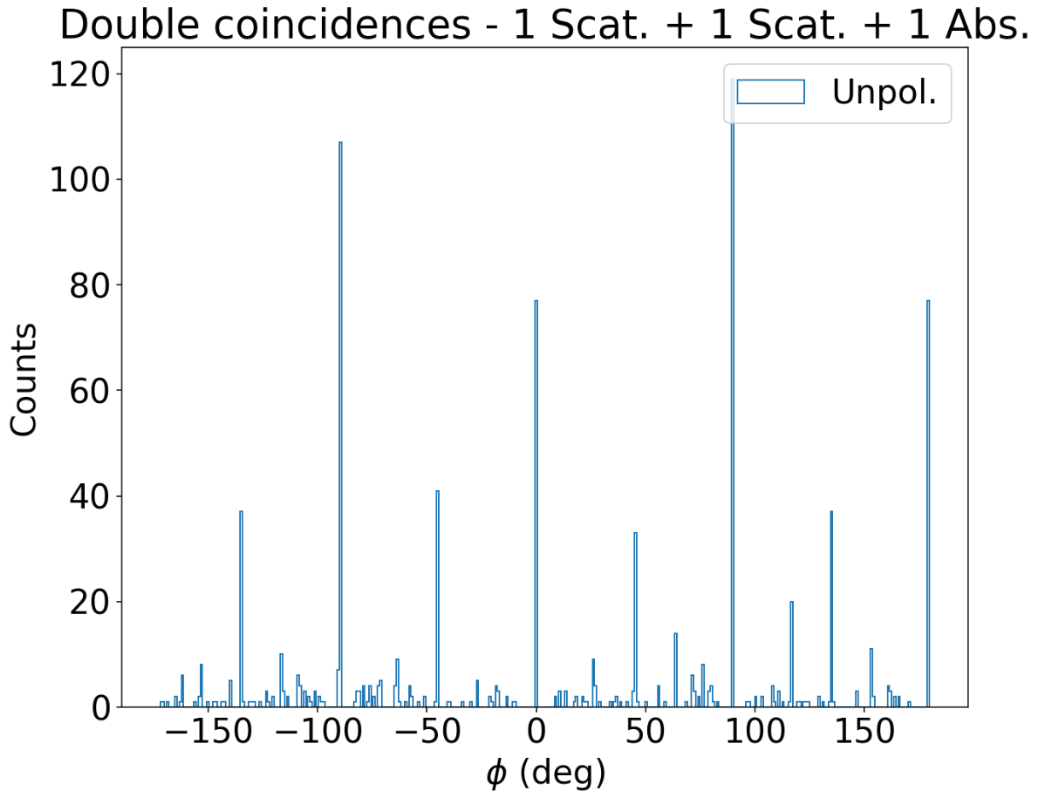
Figure 2.12: Compton scattering cross-section per unit solid angle as a funciton of θ and $\alpha = \frac{E}{mc^2}$. The cross-section decreases with increasing the scattering angle θ and for high values of α the the fall-off occurs rapidly (Davisson & Evans, 1952).



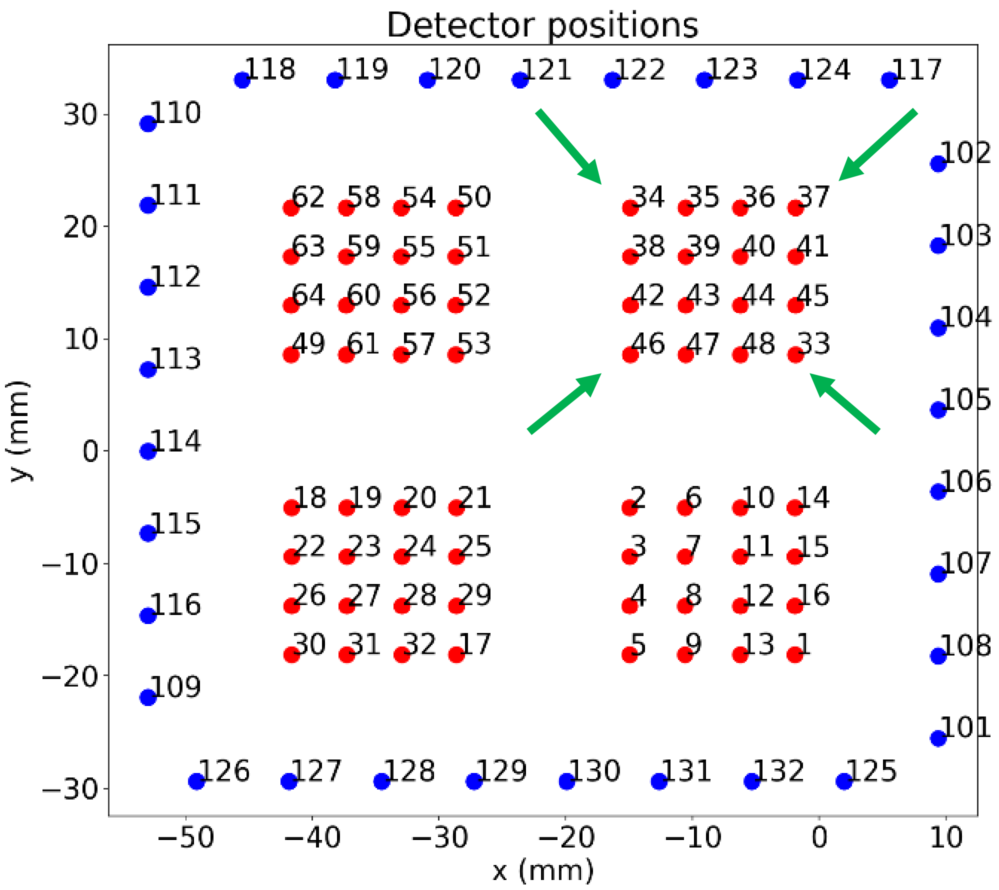
Modulation histograms

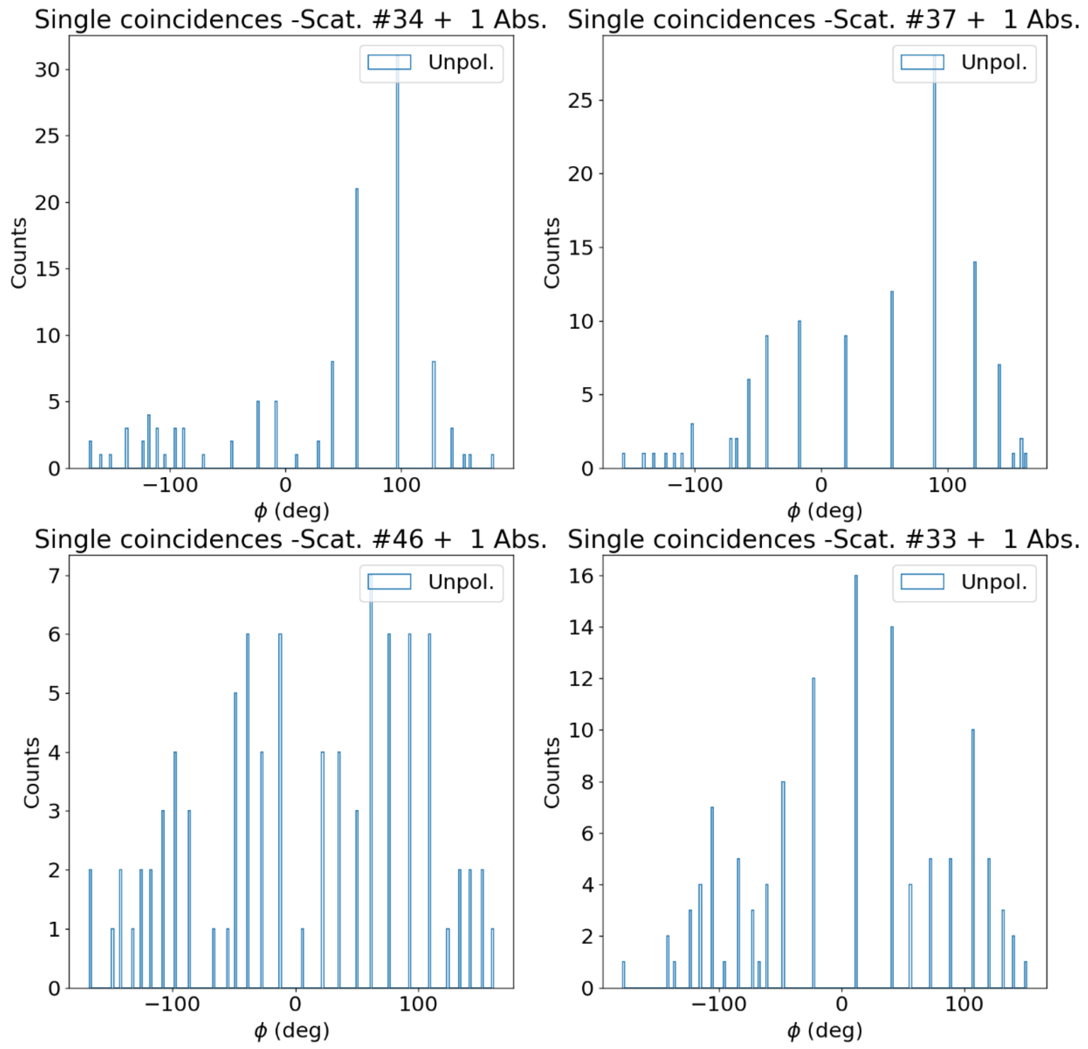
- Modulation histograms of signle and double coincidences
- All coincidences together
- Phi azimuthal angle of the first Compton interaction
- Phi = arctan(Dy/Dx),   Dx = x_abs-x_scat,   Dy=y_abs-y_scat





Single scint. bar as a polarimeter





Effectvive area

- Area eff at 60 keV with 0 keV threshold for scat. and abs. :
  - Single coinc. 0.415 cm^2
  - Double coinc. 0.055 cm^2
  - Total 0.470 cm^2 (w.r.t ~1 cm^2 estimated previously approximately)
- However, this result can be heavily affected by problems of the angular distribution of Compton scattering if present.

Analysis SW development

- How to organize sw development for data analysis? A possible heritage from IXPE experience:
  - Folder named cuspsw in the g4cusp simulation repository with files as python modules with usefull functions (with consolidated code)?
  - Folder named SendBox with subfolders for each people contributing to sw development for store work in progress scripts and jupyter notebook
  - In principle one should work in a separete branch always, but we can desice if accept to load files in personal foder in SendBox directly in the master if nedded.

Conclusions

- G4 checks to do:
  - Verify Physics List version
  - Verify materials in the mass model
  - Verify if some particoular cuts are applied
  - Verify other possible source of errors (generation of energy, writing of energy etc.)
  - Take some screenshots of the visualization of a simple simulation with a narrow pencil beam unpolarized centered on a scatterer bar at the corner. If angular distribuiton is so wrong we should see by eye a significant forward folding of scattered events
  - Simulate a toy model with a segmented ring (5 mm of height) around a central small scatterer (take also some screenshot of the visualization of the simulation)

- G4 improvements for file format (I'm proposing, not discussed at the meeting):
  - Include the polarization state in the header of the fits file
  - Include the version of the mass model in the header of the fits file