Flerov Laboratory of Nuclear Reactions, JINR, Dubna

A Monte Carlo based method for fine calibration of Si Telescopes

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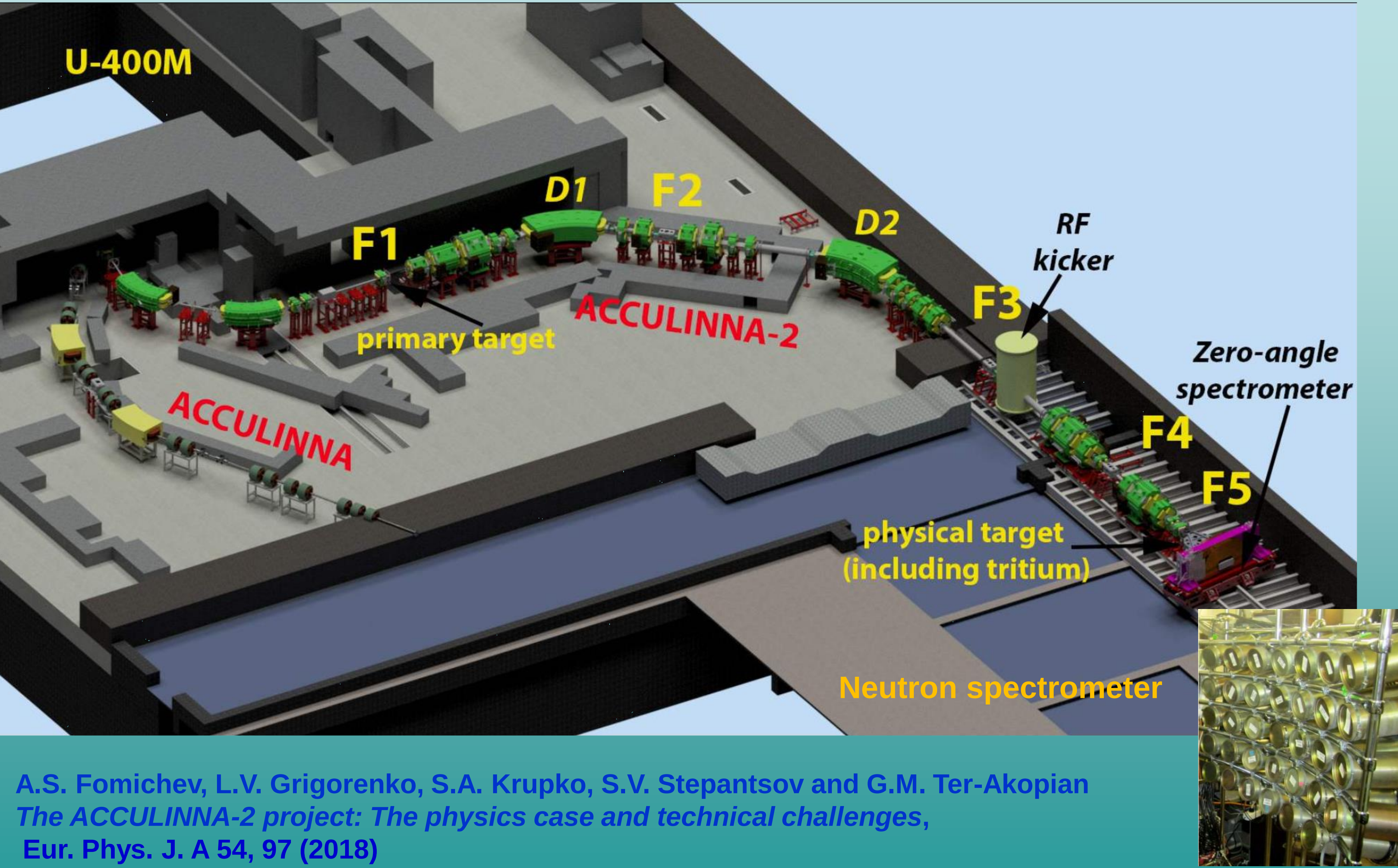
Outline

- Introduction
- Configurations and methods of calibration measurements
- Calibration results
- Discrepancies
- Summary and wish-list for Geant4

ENSAR-Geant4 workshop April 24-26. 2019, Madrid

Introduction



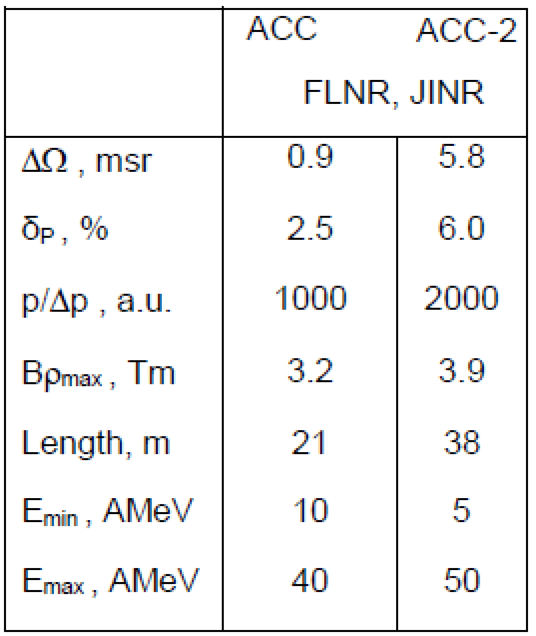
A.S. Fomichev, L.V. Grigorenko, S.A. Krupko, S.V. Stepantsov and G.M. Ter-Akopian
***The ACCULINNA-2 project: The physics case and technical challenges*,**
Eur. Phys. J. A 54, 97 (2018)

Introduction

The photo is of April 2017.
Currently the separator is hidden inside the radiation shielding and fully operational, except for the RF kicker which is just delivered

Some of the reactions to be studied soon

$d(^{8}\mathrm{He},^{3}\mathrm{He})^{7}\mathrm{H}$
$d(^{12}\mathrm{Be},^{6}\mathrm{Li})^{8}\mathrm{He}$
$d(^{11}\mathrm{Li},^{6}\mathrm{Li})^{7}\mathrm{H}$ / $^{7}\mathrm{H} \rightarrow t + 4n$
$t(^{11}\mathrm{Li},p)^{13}\mathrm{Li}$ /$^{13}\mathrm{Li}$: excit. lvls, 2n-, 4n-decays



	ACC	ACC-2
	FLNR, JINR	
$\Delta\Omega$, msr	0.9	5.8
δ_P , %	2.5	6.0
$p/\Delta p$, a.u.	1000	2000
$B\rho_{max}$, Tm	3.2	3.9
Length, m	21	38
E_{min} , AMeV	10	5
E_{max} , AMeV	40	50

Introduction

Specificity of the experiments at ACCULINNA-2.

- Low energy multiply charged ions produce big and non-constant energy loss.

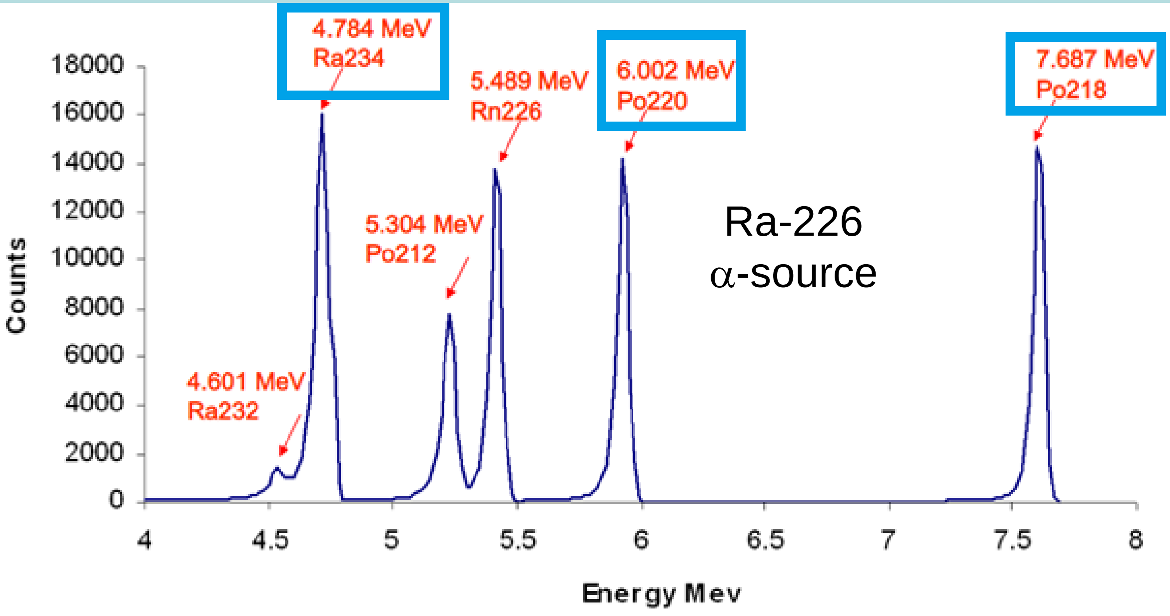
- Inevitable part of calibration procedure is to measure the dead layers of the detectors, especially Si ones (because of rel. good energy resolution)

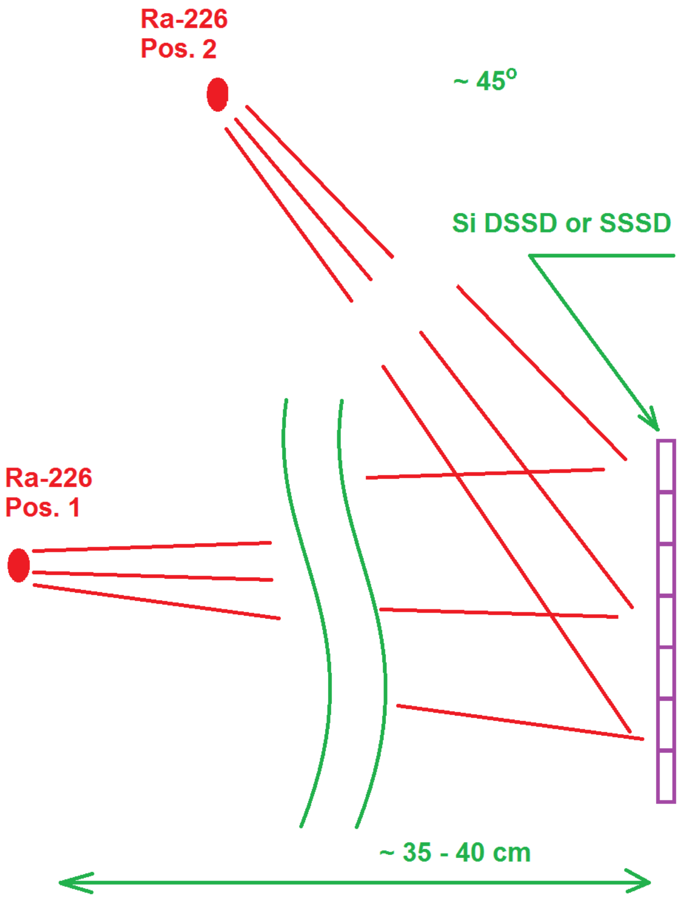
- For DeltaE-E discrimination a thin Si detector is used which is substantially non-uniform

- All together require calibration measurements with high statistics and should be supported by reliable MC simulations.

Configurations and methods of calibration measurements

1) Traditional approach. Big distance, separate measurements for the dead layers.





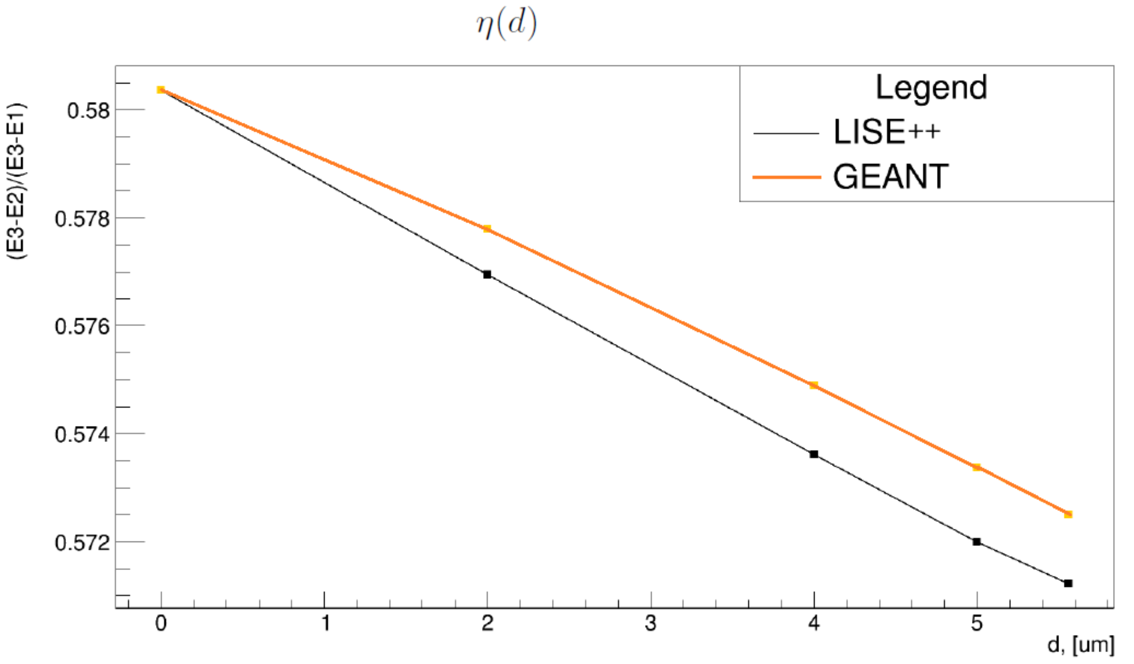
Shift of peaks is due to increasing range of α-particles in the dead layer. **Drawbacks:** long measurement ~12h; different thickness of the dead layer is found for different peaks; possible small change of the amplification after switching OFF and ON matters; depends on the energy loss calculation method (we compared LISE++ and Geant4).

Configurations and methods of calibration measurements

2) Alternative approach. Simultaneous measurement for dead layers and calibration. Lines of 4.7844 MeV, 6.0024 MeV, 7.6869 MeV are used.

Let’s consider the following dimensionless ratio:

$\eta(d) = \dfrac{E_3 - E_2}{E_3 - E_1}$, where E_1, E_2 and E_3 are the energies of alpha particles with initial energies 4.7844, 6.0024 and 7.6869 MeV respectevely, after propagation through the dead layer with thickness d [μm].



If the response function of each strip is linear (Edep=a*N_{ADC}+b), then η = η_{ex}

$$\eta_{exp}(d) = \frac{N_3 - N_2}{N_3 - N_1}$$

There is still a discrepancy between Geant4 and LISE++ Eloss calculations.

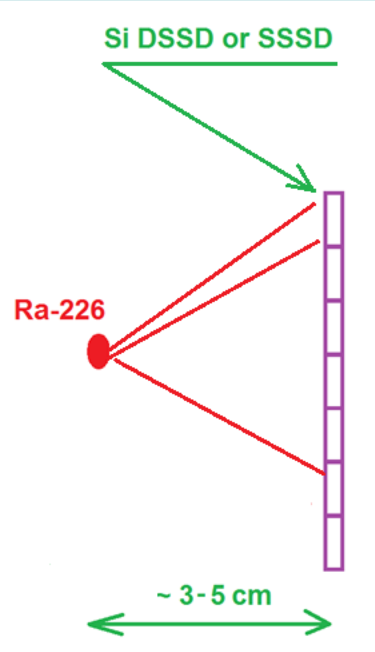
After *d* is found, calibration can be easily accomplished.

Implausible *d* is a sign of nonlinearity

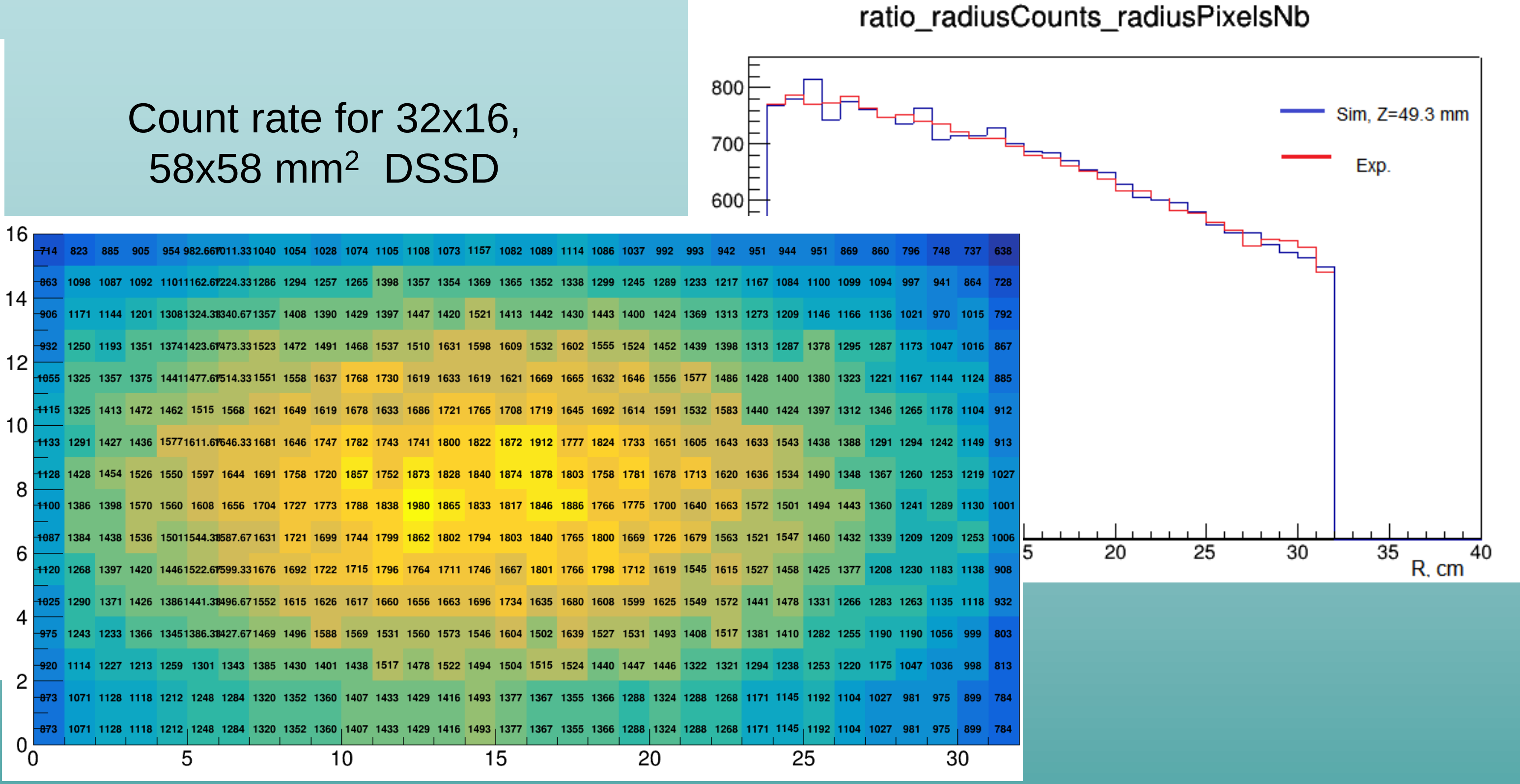
A combined method with 2 sources at different incidence angles is proposed for the future for handling weak non-linearities.

Configurations and methods of calibration measurements

3) “Even more alternative” approach. The source is placed much closer. Simultaneous measurement for dead layers and calibration. Lines of 4.7844 MeV, 6.0024 MeV, 7.6869 MeV are used.



Count rate for 32x16, 58x58 mm^2 DSSD

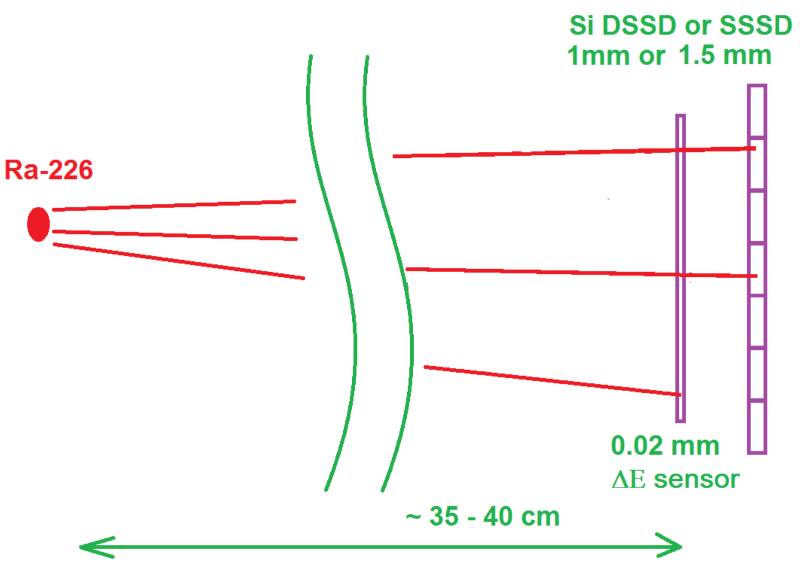


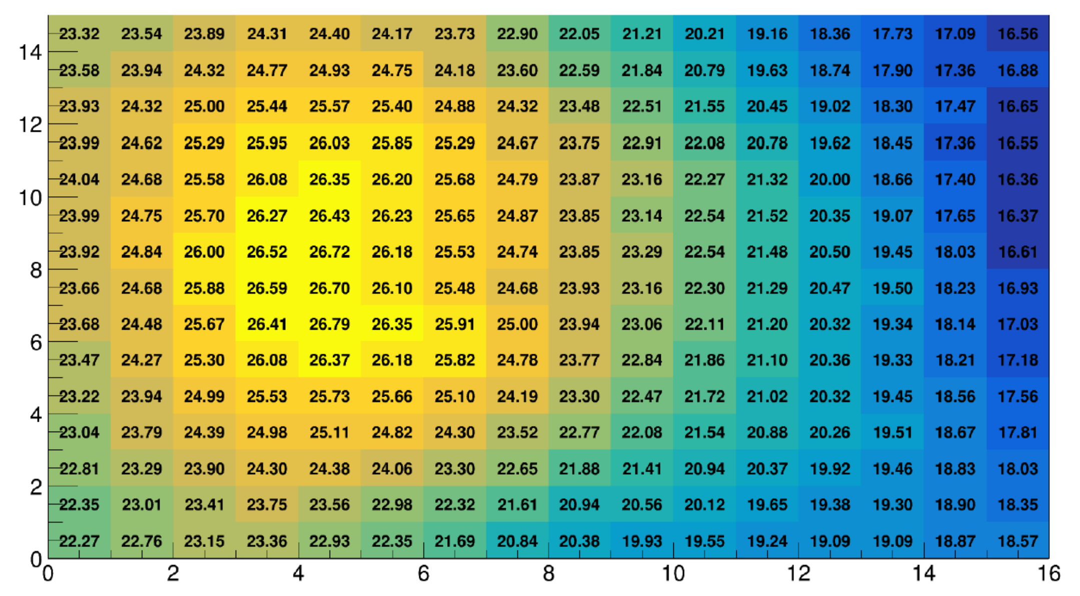
714	823	885	905	954	982.667	1011.33	1040	1054	1028	1074	1105	1108	1073	1157	1082	1089	1114	1086	1037	992	993	942	951	944	951	869	860	796	748	737	638
863	1098	1087	1092	1101	1162.67	1224.33	1286	1294	1257	1265	1398	1357	1354	1369	1365	1352	1338	1299	1245	1289	1233	1217	1167	1084	1100	1099	1094	997	941	864	728
906	1171	1144	1201	1308	1324.33	1340.67	1357	1408	1390	1429	1397	1447	1420	1521	1413	1442	1430	1443	1400	1424	1369	1313	1273	1209	1146	1166	1136	1021	970	1015	792
932	1250	1193	1351	1374	1423.67	1473.33	1523	1472	1491	1468	1537	1510	1631	1598	1609	1532	1602	1555	1524	1452	1439	1398	1313	1287	1378	1295	1287	1173	1047	1016	867
1055	1325	1357	1375	1441	1477.67	1514.33	1551	1558	1637	1768	1730	1619	1633	1619	1621	1669	1665	1632	1646	1556	1577	1486	1428	1400	1380	1323	1221	1167	1144	1124	885
1115	1325	1413	1472	1462	1515	1568	1621	1649	1619	1678	1633	1686	1721	1765	1708	1719	1645	1692	1614	1591	1532	1583	1440	1424	1397	1312	1346	1265	1178	1104	912
1133	1291	1427	1436	1577	1611.67	1646.33	1681	1646	1747	1782	1743	1741	1800	1822	1872	1912	1777	1824	1733	1651	1605	1643	1633	1543	1438	1388	1291	1294	1242	1149	913
1128	1428	1454	1526	1550	1597	1644	1691	1758	1720	1857	1752	1873	1828	1840	1874	1878	1803	1758	1781	1678	1713	1620	1636	1534	1490	1348	1367	1260	1253	1219	1027
1100	1386	1398	1570	1560	1608	1656	1704	1727	1773	1788	1838	1980	1865	1833	1817	1846	1886	1766	1775	1700	1640	1663	1572	1501	1494	1443	1360	1241	1289	1130	1001
1087	1384	1438	1536	1501	1544.33	1587.67	1631	1721	1699	1744	1799	1862	1802	1794	1803	1840	1765	1800	1669	1726	1679	1563	1521	1547	1460	1432	1339	1209	1209	1253	1006
1120	1268	1397	1420	1446	1522.67	1599.33	1676	1692	1722	1715	1796	1764	1711	1746	1667	1801	1766	1798	1712	1619	1545	1615	1527	1458	1425	1377	1208	1230	1183	1138	908
1025	1290	1371	1426	1386	1441.33	1496.67	1552	1615	1626	1617	1660	1656	1663	1696	1734	1635	1680	1608	1599	1625	1549	1572	1441	1478	1331	1266	1283	1263	1135	1118	932
975	1243	1233	1366	1345	1386.33	1427.67	1469	1496	1588	1569	1531	1560	1573	1546	1604	1502	1639	1527	1531	1493	1408	1517	1381	1410	1282	1255	1190	1190	1056	999	803
920	1114	1227	1213	1259	1301	1343	1385	1430	1401	1438	1517	1478	1522	1494	1504	1515	1524	1440	1447	1446	1322	1321	1294	1238	1253	1220	1175	1047	1036	998	813
873	1071	1128	1118	1212	1248	1284	1320	1352	1360	1407	1433	1429	1416	1493	1377	1367	1355	1366	1288	1324	1288	1268	1171	1145	1192	1104	1027	981	975	899	784
873	1071	1128	1118	1212	1248	1284	1320	1352	1360	1407	1433	1429	1416	1493	1377	1367	1355	1366	1288	1324	1288	1268	1171	1145	1192	1104	1027	981	975	899	784

Measurements at a small distance are much faster. However in order to take into account correctly the distribution of ranges of α-particle in the dead layer of each “pixel”, simulations are used. This distribution depends on the incidence angle.

Configurations and methods of calibration measurements

4) Calibration of a telescope consisting of a thin ΔE detector assembled together with a thick one. Lines of 4.7844 MeV, 6.0024 MeV, 7.6869 MeV are used.





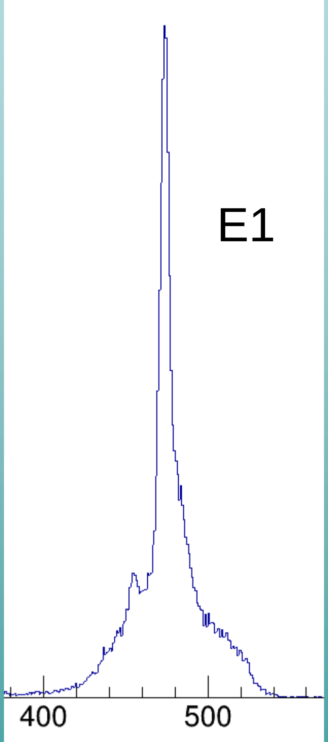
23.32	23.54	23.89	24.31	24.40	24.17	23.73	22.90	22.05	21.21	20.21	19.16	18.36	17.73	17.09	16.56
23.58	23.94	24.32	24.77	24.93	24.75	24.18	23.60	22.59	21.84	20.79	19.63	18.74	17.90	17.36	16.88
23.93	24.32	25.00	25.44	25.57	25.40	24.88	24.32	23.48	22.51	21.55	20.45	19.02	18.30	17.47	16.65
23.99	24.62	25.29	25.95	26.03	25.85	25.29	24.67	23.75	22.91	22.08	20.78	19.62	18.45	17.36	16.55
24.04	24.68	25.58	26.08	26.35	26.20	25.68	24.79	23.87	23.16	22.27	21.32	20.00	18.66	17.40	16.36
23.99	24.75	25.70	26.27	26.43	26.23	25.65	24.87	23.85	23.14	22.54	21.52	20.35	19.07	17.65	16.37
23.92	24.84	26.00	26.52	26.72	26.18	25.53	24.74	23.85	23.29	22.54	21.48	20.50	19.45	18.03	16.61
23.66	24.68	25.88	26.59	26.70	26.10	25.48	24.68	23.93	23.16	22.30	21.29	20.47	19.50	18.23	16.93
23.68	24.48	25.67	26.41	26.79	26.35	25.91	25.00	23.94	23.06	22.11	21.20	20.32	19.34	18.14	17.03
23.47	24.27	25.30	26.08	26.37	26.18	25.82	24.78	23.77	22.84	21.86	21.10	20.36	19.33	18.21	17.18
23.22	23.94	24.99	25.53	25.73	25.66	25.10	24.19	23.30	22.47	21.72	21.02	20.32	19.45	18.56	17.56
23.04	23.79	24.39	24.98	25.11	24.82	24.30	23.52	22.77	22.08	21.54	20.88	20.26	19.51	18.67	17.81
22.81	23.29	23.90	24.30	24.38	24.06	23.30	22.65	21.88	21.41	20.94	20.37	19.92	19.46	18.83	18.03
22.35	23.01	23.41	23.75	23.56	22.98	22.32	21.61	20.94	20.56	20.12	19.65	19.38	19.30	18.90	18.35
22.27	22.76	23.15	23.36	22.93	22.35	21.69	20.84	20.38	19.93	19.55	19.24	19.09	19.09	18.87	18.57

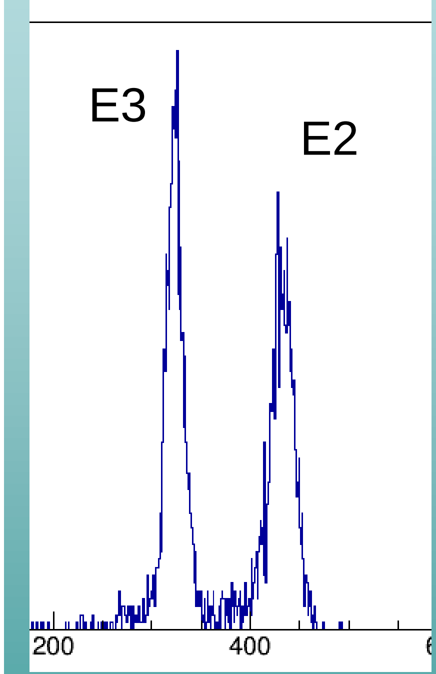
First task is to measure the passive thickness of the ΔE detector. One can use the η-ratio or shift of the peaks w.r.t measurements without the ΔE detector. In the last case the obtained thickness slightly depends on the chosen initial energy of α-particles and in neither case coincide with measurement based on the η-ratio. However the difference is not more than 1.5 micron

Configurations and methods of calibration measurements

4) Calibration of the thin ΔE detector assembled together with a thick one. Lines of 4.7844 MeV, 6.0024 MeV, 7.6869 MeV are used.

The second task is calibration of the ΔE detector itself. Each readout channel corresponds to a strip with non-constant thickness. We consider the thickest and the thinnest “pixels” of the strip.

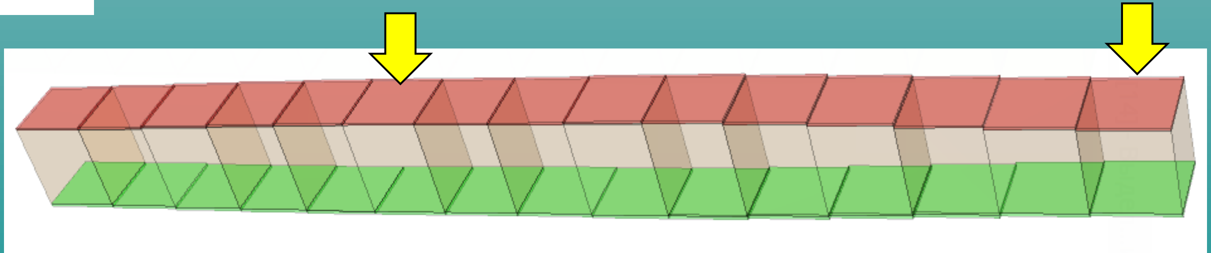




Case 1. 4.784 MeV alphas stop in the sensor, others go through.
E1 – Eloss of the stopped particles
E2, E3 –Eloss in the thick “pixel”,
E2’, E3’ – in the thin one

Case 2. All three lines of interest go through the ΔE detector.

E1, E2, E3 –Eloss in the thick “pixel”,
E1’, E2’, E3’ – in the thin one



Configurations and methods of calibration measurements

4) Calibration of the thin ΔE detector assembled together with a thick one. Lines of 4.7844 MeV, 6.0024 MeV, 7.6869 MeV are used.

The second task is calibration of the ΔE detector itself. Each readout channel corresponds to a strip with non-constant thickness. Consider the thickest and the thinnest pixel of the strip.

We can compute and compare with simulation several dimensionless ratios
η_1 =(E1-E2)/(E1-E3), η_2 =(E2-E2')/(E3-E3'); η_3 =(E2'-E3')/(E2-E3); η_4 =(E2'-E3)/(E2-E3').

η_1-ratio allows to determine the active thickness of a "pixel" if the front dead layer is known

There is no time to go into detail, but…

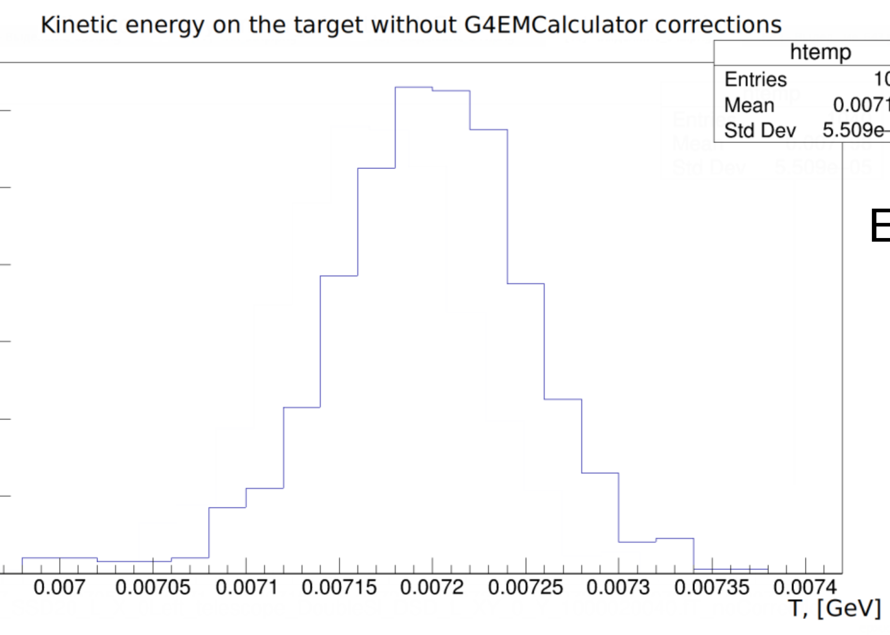
- There is a discrepancy between LISE++. Geant4 and experiment.
- Geant4 is closer to the experiment.
- There is no sensitivity to the dead layers (to be measured separately)
- In the case 2 when all alphas pass through the conclusions are the same

Expected d_{Active}(μm)↓	Pseudo-pixel	Calc. η_1 LISE	Calc. η_1 Geant4	Experim. η_1	Calc. d_{Act} Geant4
15.16	X15Y10	0.5711	0.5606	0.5628	15.36
15.89	X14Y14	0.5768	0.5699	0.5527	14.51
17.37	X15Y0	0.5910	0.5895	0.5807	16.73
17.70	X14Y1	0.5948	0.5938	0.5783	16.52

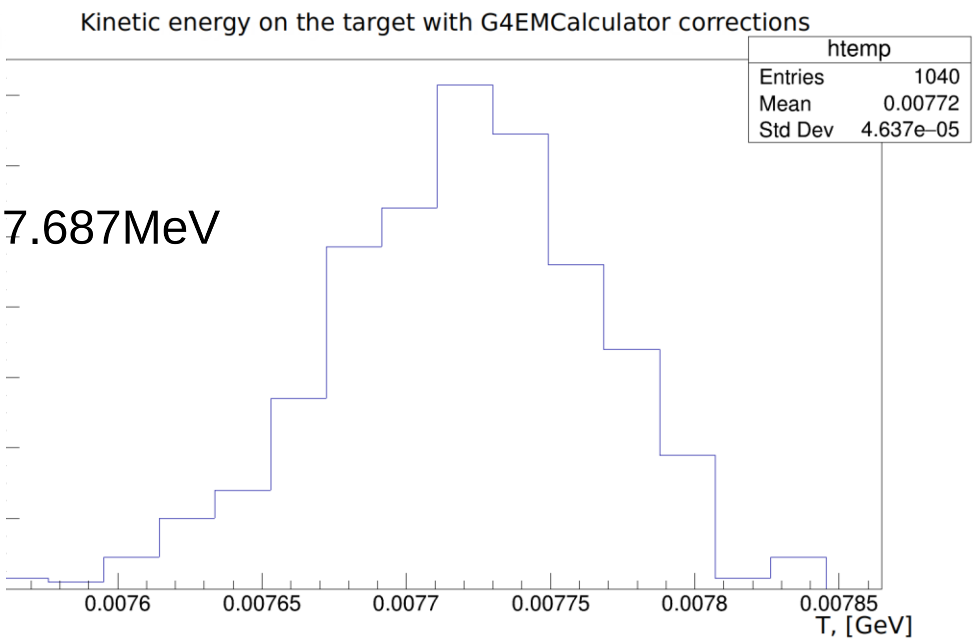
Calibration results

For the working version of calibration we decided to rely on the passive thickness measurements via shift of the most energetic alpha line, assumed the front dead layer to be 0.5 micron (+0.3 micron at the source) and used the active thickness calculated via η_1-ratio for thicker strips where the 4.78 MeV alphas stop. The achieved accuracy is not worse than 4 keV. For thinner strips we assumed in addition the back dead layer to be 0.7 micron and achieved quality of calibration is worse, up to 68 keV (no optimization is applied).

Reconstruction of energy in a telescope requires reverse tracking of a particle, taking into account the dead layers. This procedure is realized within the ExpertRoot framework(talk by Mikhail Kozlov tomorrow).


Kinetic energy on the target without G4EMCalculator corrections

E= 7.687MeV


Kinetic energy on the target with G4EMCalculator corrections

Discrepancies

In this slide the observed discrepancies are listed as well as possible reasons.
Some of the reasons may be relevant for Geant4

- MC based measurements of the passive thickness of the thin ΔE detector do not match each other well enough. (instability of the calibration; non-linearity of the response; inaccuracy of the Eloss simulation for low energy ions, wrong understanding of the dead layer)

- MC based measurements of the active thickness of the thin ΔE detector do not match each other well enough. (inaccuracy of the Eloss simulation for low energy ions, wrong understanding of the dead layer)

- G4EMCalculator seems to overestimate losses w.r.t simulation for a few keV

- Spread of Eloss in the thin ΔE detector is bigger than expected from simulations taking into account thickness nonumiformity and resolution lf the detector (inaccuracy of the simulations of the Eloss fluctuations, detector surface is less smooth that we think, wrong understanding of the dead layer)

Summary and wish-list for Geant4

A Monte Carlo based method for fine calibration of Si Telescopes is developed. It is sensitive to accuracy of the energy loss simulations and to imperfectness (of different nature) of the detector. For improving the quality of the calibration it is desirable to decouple validation of the simulation from the other factors. Our wish-list is completely about validation.

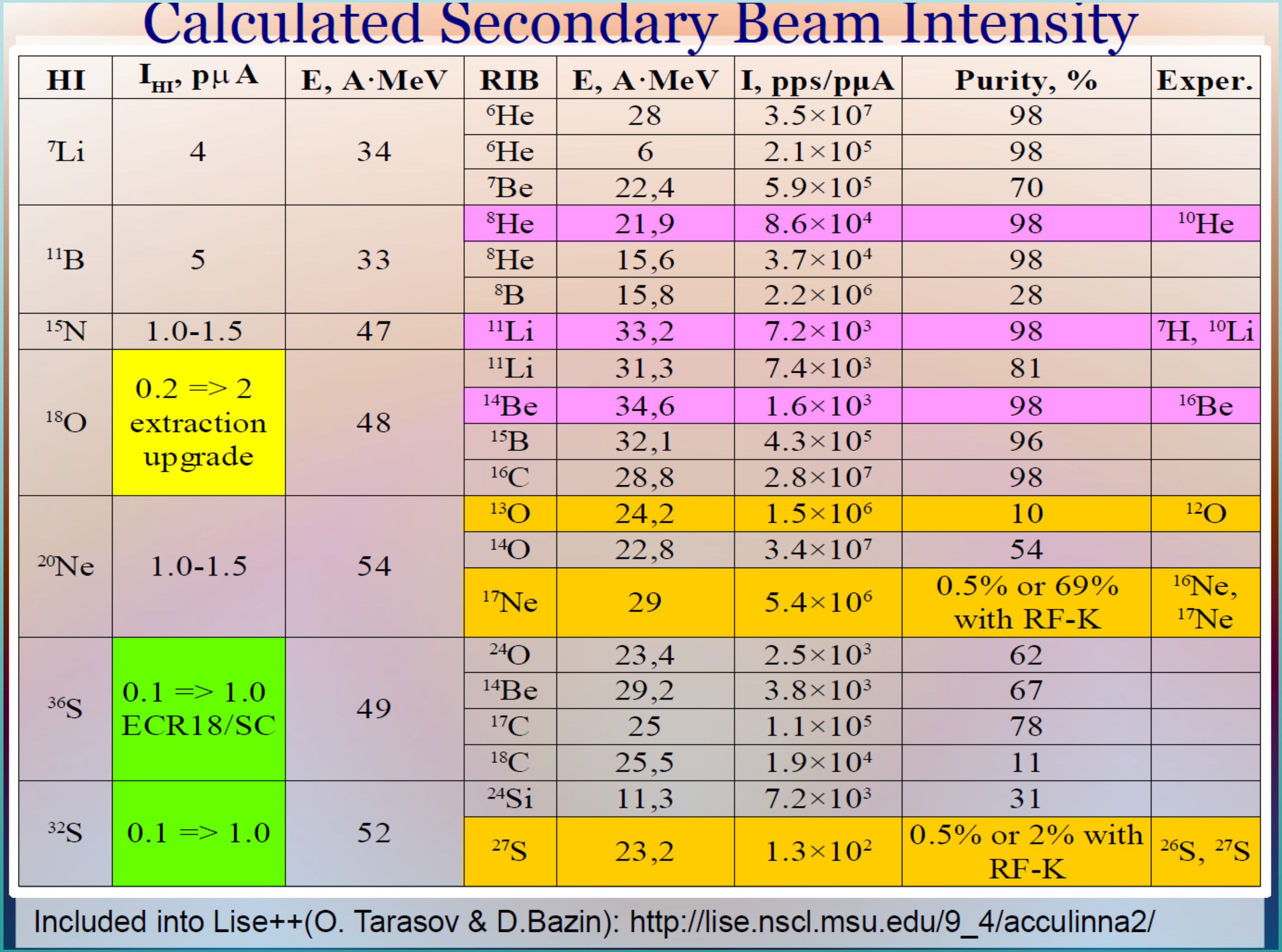
- It would be nice to have a clear navigation through all the accomplished works concerning validation of the energy loss, struggling and multiple scattering models in G4 for low energy multiply charged ions

- The G4 site could be a place where the information about all planned and ongoing validation activities is concentrated.

- We would be happy to join validation activity coordinated by the G4 physics experts.

Thank you for your attention

backups



Calculated Secondary Beam Intensity

HI	I_{HI}, pμA	E, A·MeV	RIB	E, A·MeV	I, pps/pμA	Purity, %	Exper.
^{7}Li	4	34	^{6}He	28	3.5×10^{7}	98	
			^{6}He	6	2.1×10^{5}	98	
			^{7}Be	22,4	5.9×10^{5}	70	
^{11}B	5	33	^{8}He	21,9	8.6×10^{4}	98	^{10}He
			^{8}He	15,6	3.7×10^{4}	98	
			^{8}B	15,8	2.2×10^{6}	28	
^{15}N	1.0-1.5	47	^{11}Li	33,2	7.2×10^{3}	98	^{7}H, ^{10}Li
^{18}O	0.2 => 2 extraction upgrade	48	^{11}Li	31,3	7.4×10^{3}	81	
			^{14}Be	34,6	1.6×10^{3}	98	^{16}Be
			^{15}B	32,1	4.3×10^{5}	96	
			^{16}C	28,8	2.8×10^{7}	98	
^{20}Ne	1.0-1.5	54	^{13}O	24,2	1.5×10^{6}	10	^{12}O
			^{14}O	22,8	3.4×10^{7}	54	
			^{17}Ne	29	5.4×10^{6}	0.5% or 69% with RF-K	^{16}Ne, ^{17}Ne
^{36}S	0.1 => 1.0 ECR18/SC	49	^{24}O	23,4	2.5×10^{3}	62	
			^{14}Be	29,2	3.8×10^{3}	67	
			^{17}C	25	1.1×10^{5}	78	
			^{18}C	25,5	1.9×10^{4}	11	
^{32}S	0.1 => 1.0	52	^{24}Si	11,3	7.2×10^{3}	31	
			^{27}S	23,2	1.3×10^{2}	0.5% or 2% with RF-K	^{26}S, ^{27}S

Included into Lise++(O. Tarasov & D.Bazin): http://lise.nscl.msu.edu/9_4/acculinna2/

backups

Dead (μm)→ η_i ↓ (strip 6)	0	0.5	0.8	1.0	Exp. strip 6	Geant4 Dead 0.8	Exp. strip 7	G4 d0.8 strip7
η_2	1.559	1.558	1.558	1.558	1.587	1.575	1.526	1.529
η_3	0.666	0.665	0.666	0.665	0.659	0.6617	0.6823	0.6819
η_4	0.438	0.0416	0.0417	0.0397	0.0500	0,0466	0,0486	0.0498

Dead (μm)→ Active(μm)↓	0	0.5	0.8	1.0	Exp. X0Y6	Exp. X6Y6	Geant4 Dead 0.8
20.08				0.6647	0.6638	0.2759	
20.284			0.6639				
20.491	-	-	-	-			0,6639
20.568		0.6639					
21.04	0.6632						
24.35				0.2761			
24.558			0.2759				
24.753	-	-	-	-			0,2759
24.87		0.2759					
25.39	0.2763						
Above: η_1 values; below: calculated back dead layer							
Back dead X0Y6 (μm)	-	0.92	0.91	0.91	-	-	0.70
Back dead X6Y6 (μm)	-	0.84	0.85	0.86	-	-	0.68