Radioactive background measurements @ MIB

JUNO-Italia meeting
Ferrara, 9-10 maggio 2019

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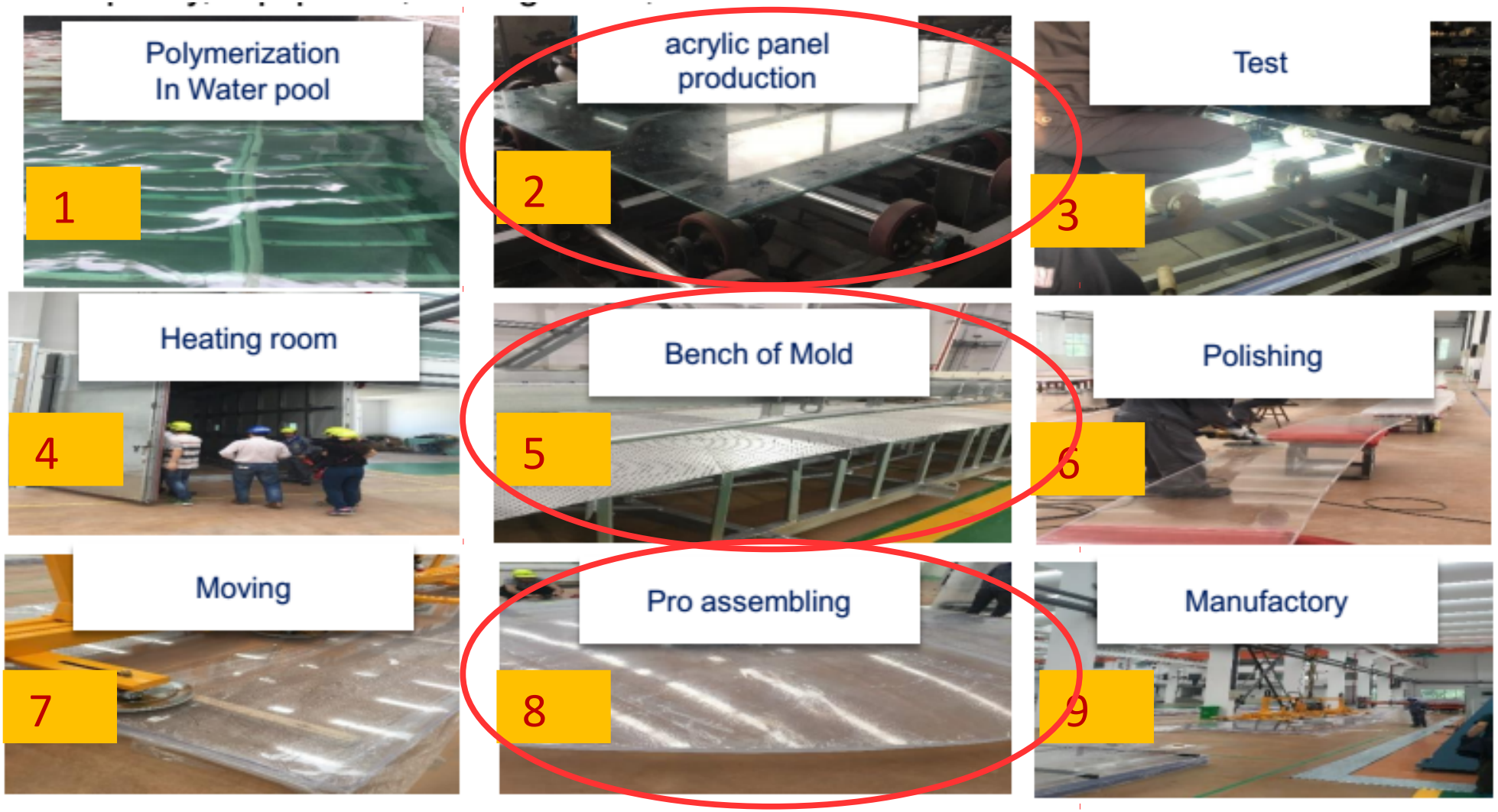
ACRYLIC RADIOPURITY

Neutron Activation Analysis on Donchamp Acrylic

- We received from our Chinese colleagues few panels from Donchamp at different steps of the production process:

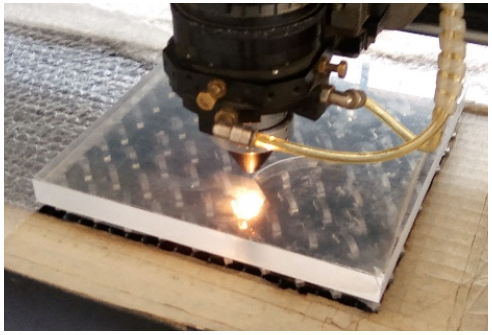
Neutron Activation Analysis on Donchamp Acrylic

- All panels we received have been polished on the surfaces.
- We decided to start the measurements of the samples from the last step (#8). Then we measured the others.

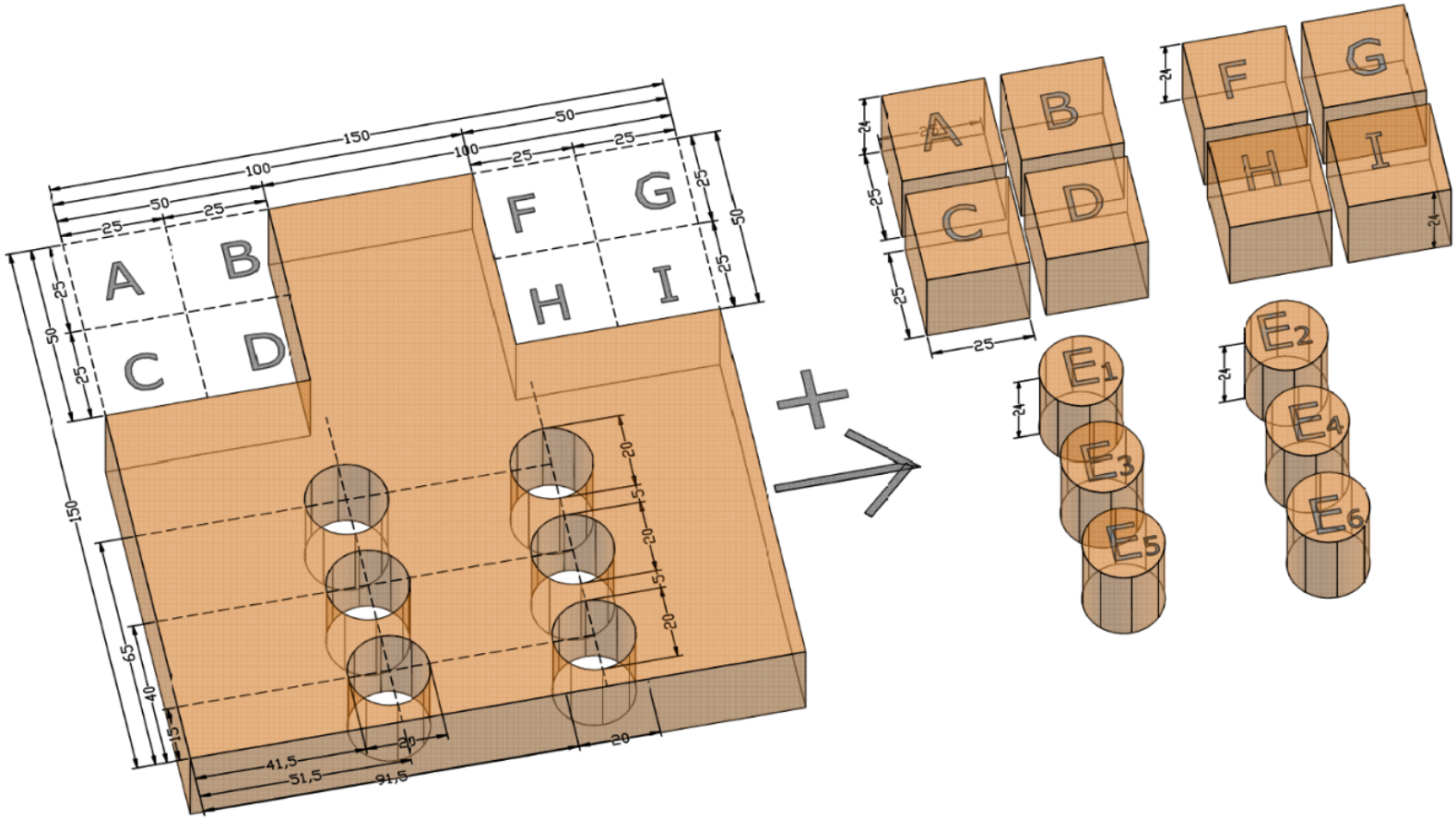


Neutron Activation Analysis on Donchamp Acrylic

- We have brought the pieces to the usual company for laser cutting



mass ~ 8g



- The small cylinders are the samples used for neutron irradiation: they are cut at the level of the bonding among different panels of step #8 (Donchamp panel n.3)

Neutron Activation Analysis on Donchamp Acrylic

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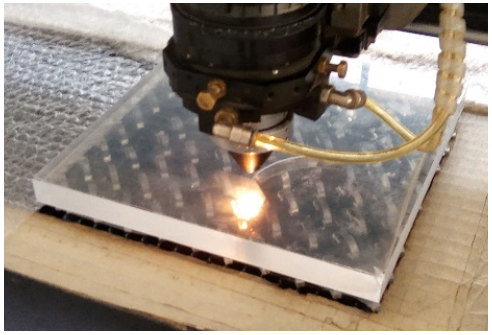
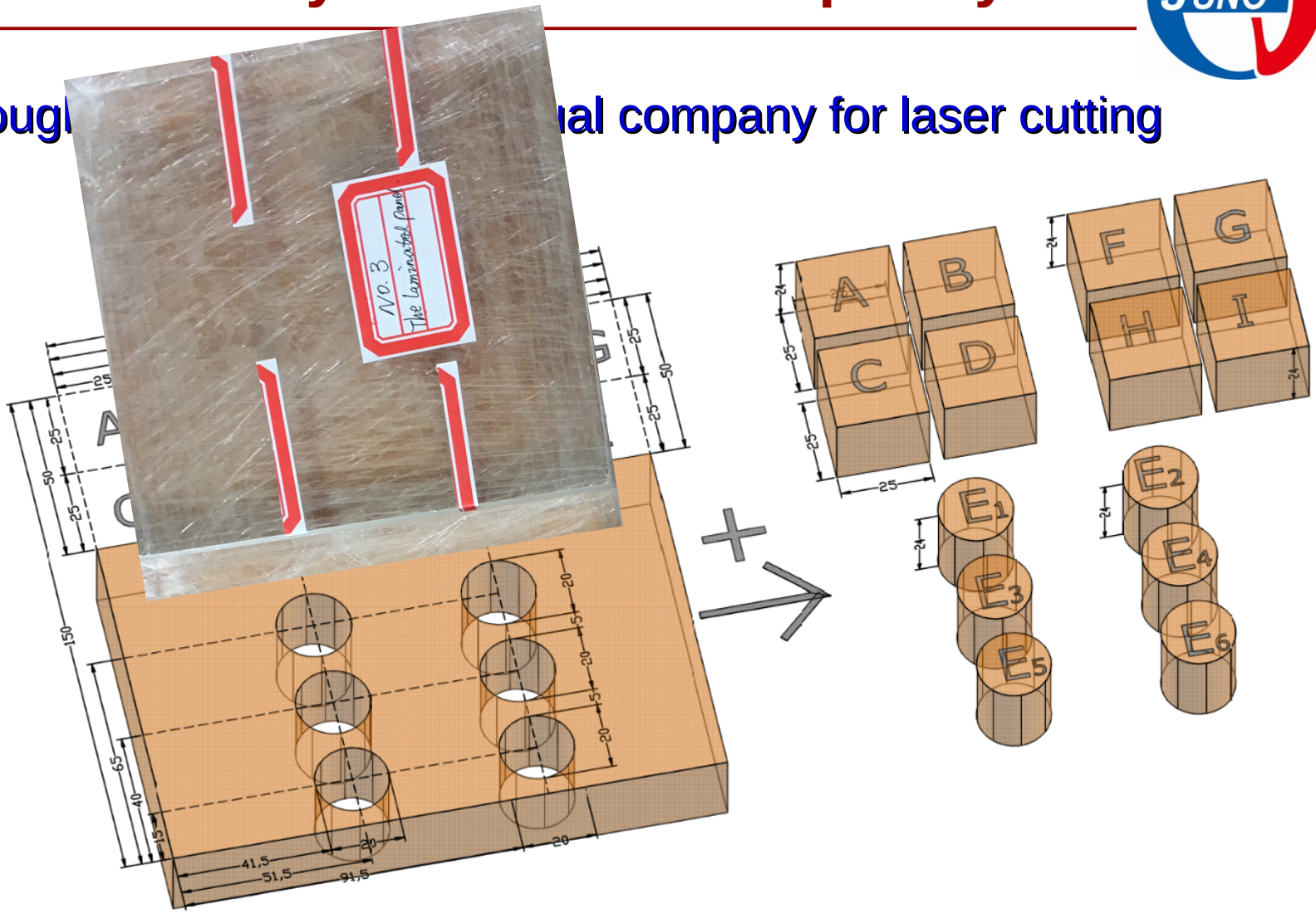


mass ~ 8g



- The small cylinders are the samples used for neutron irradiation: they are cut at the level of the bonding among different panels of step #8 (Donchamp panel n.3)

Neutron Activation Analysis on Donchamp Acrylic

- Samples have been prepared for the neutron irradiation in clean room: they have been washed in Ultrasonic bath with demineralized water. Sample containers have been cleaned with nitric acid.

^{40}K: Neutron Activation Analysis results

JUNO request: < 1E-12 g/g

	^{40}K – pre [1E-12 g/g]	^{40}K – post [1E-12 g/g]
PANEL 1 (step2) – sample E3	0.37 ± 0.05	< 0.16
PANEL 2 (step5) – sample E3	0.39 ± 0.12	--
PANEL 2 (step5) – sample E1	0.21 ± 0.04	< 0.016
PANEL 3 (step8) – sample E1	2.66 ± 0.34	1.27 ± 0.13
PANEL 3 (step8) – sample E3	3.60 ± 0.33	2.15 ± 0.49
PANEL 3 (step8) – sample E4	1.23 ± 0.11	--
PANEL 4 (step8) – sample E3	1.01 ± 0.12	--

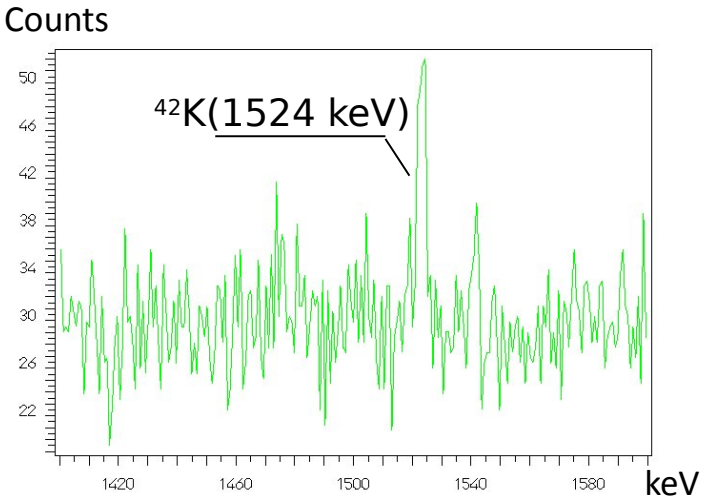
after removing some thickness from the surface (~1g total)

mass of each sample ~ 8g

^{40}K: Neutron Activation Analysis results

- A small ^{40}K contamination is present in **all** samples.
  However, in panels 1 and 2 it seems to be only on the surface of the panel (and smaller than the radiopurity request for JUNO).

- On the other hand, it looks like the process of bonding two or more panels adds ^{40}K to the Acrylic sample, in the bulk of the sample.
  This is true for both bonding along the side or along the thickness.



- There seems to be also a slight dependence of the ^{40}K contamination on the position of the sample within the panel.

^{232}Th and ^{238}U: Neutron Activation Analysis results

JUNO request: < 1E-12 g/g

limits @ 90% C.L.

	^{238}U [1E-12 g/g]	^{232}Th [1E-12 g/g]
PANEL 1 (step2) – sample E3	< 1.4*	< 2.5*
PANEL 2 (step5) – sample E1	< 0.31*	< 0.49*
PANEL 3 (step8) – sample E5	< 1.4	< 1.4
PANEL 4 (step8) – sample E3	< 1.3	--

mass of each sample ~ 8g

*after surface removal

No ^{238}U and ^{232}Th contaminations are found in all production steps

this time we could use a more sensitive HPGe

Neutron Activation Analysis on Donchamp Acrylic

Conclusions

- Donchamp Acrylic seems compliant with JUNO requests, apart from a ^{40}K contamination that is critical after the process of bonding two or more panels.
- A check on the ^{226}Ra contamination (that was found on the first screening panels) must be done: ad hoc samples should be prepared together with CD group.
- More investigations can be done in the next months to control the mass production.

ACRYLIC SURFACE

Acrylic samples for alpha measurements

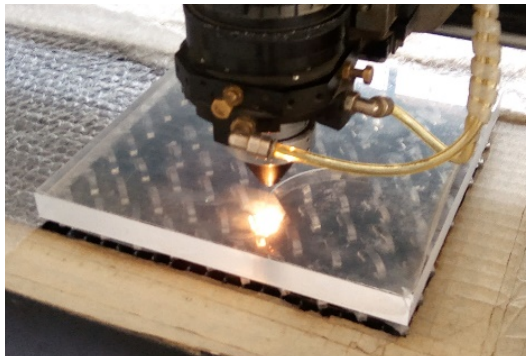
Silicon Barrier Detectors

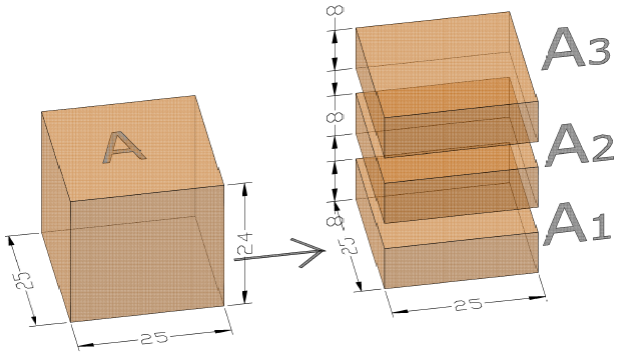
- Silicon detector
- Low-Bkg
- 900mm^2

Sentitivity: 10^{-7} – 10^{-8}Bq/cm^2

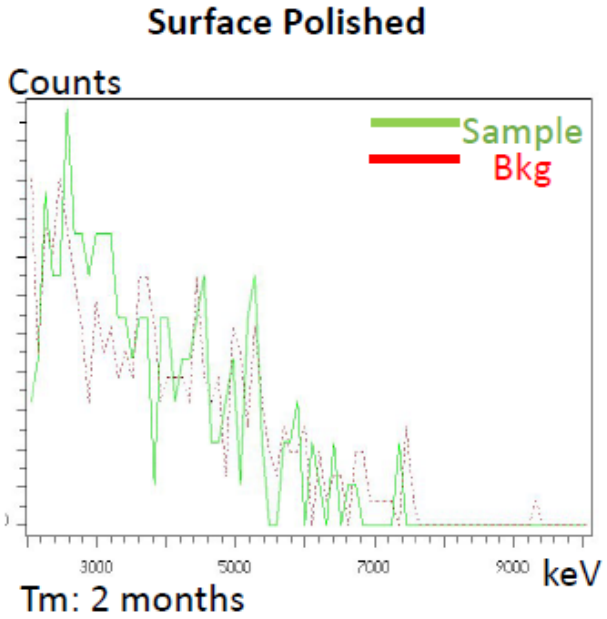
Layer 5: one surface is been polished and the other not

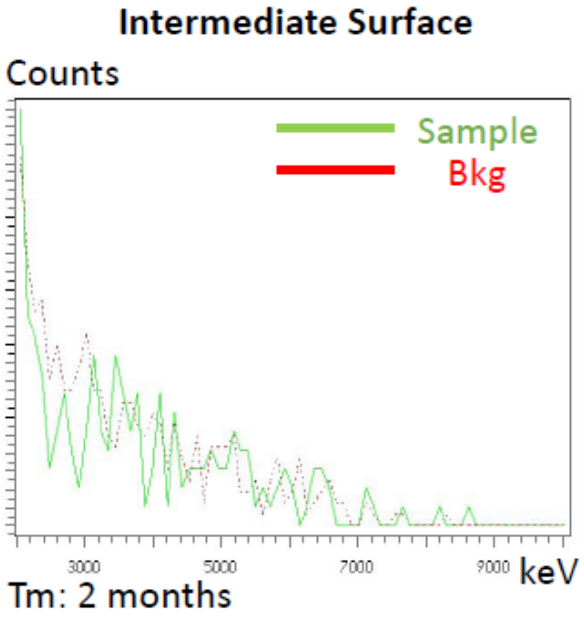
→ We perfomed measurements on three different surfaces

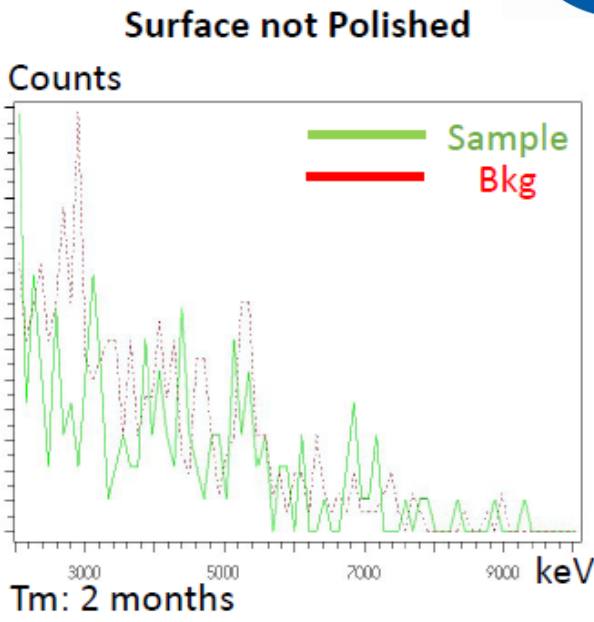




Alpha measurement results







	Surface Polished		Intermediate Surface		Surface not Polished	
Thickness	^{232}Th[Bq/cm^2]	^{238}U[Bq/cm^2]	^{232}Th[Bq/cm^2]	^{238}U[Bq/cm^2]	^{232}Th[Bq/cm^2]	^{238}U[Bq/cm^2]
10nm	$<2\cdot10^{-7}$	$<3\cdot10^{-7}$	$<6\cdot10^{-7}$	$<5\cdot10^{-7}$	$<8\cdot10^{-7}$	$<8\cdot10^{-7}$
100nm	$<3\cdot10^{-8}$	$<1\cdot10^{-7}$	$<5\cdot10^{-8}$	$<3\cdot10^{-7}$	$<8\cdot10^{-8}$	$<4\cdot10^{-7}$
1um	$<2\cdot10^{-7}$	$<2\cdot10^{-7}$	$<4\cdot10^{-7}$	$<3\cdot10^{-7}$	$<6\cdot10^{-7}$	$<4\cdot10^{-7}$
10um	$<6\cdot10^{-7}$	$<1\cdot10^{-6}$	$<1\cdot10^{-6}$	$<2\cdot10^{-6}$	$<2\cdot10^{-6}$	$<3\cdot10^{-6}$
100um	$<6\cdot10^{-6}$	$<1\cdot10^{-5}$	$<1\cdot10^{-5}$	$<2\cdot10^{-5}$	$<1\cdot10^{-5}$	$<3\cdot10^{-5}$

CL. 90%

Results for all samples are compatible with the detector background

SIMULATION WORK

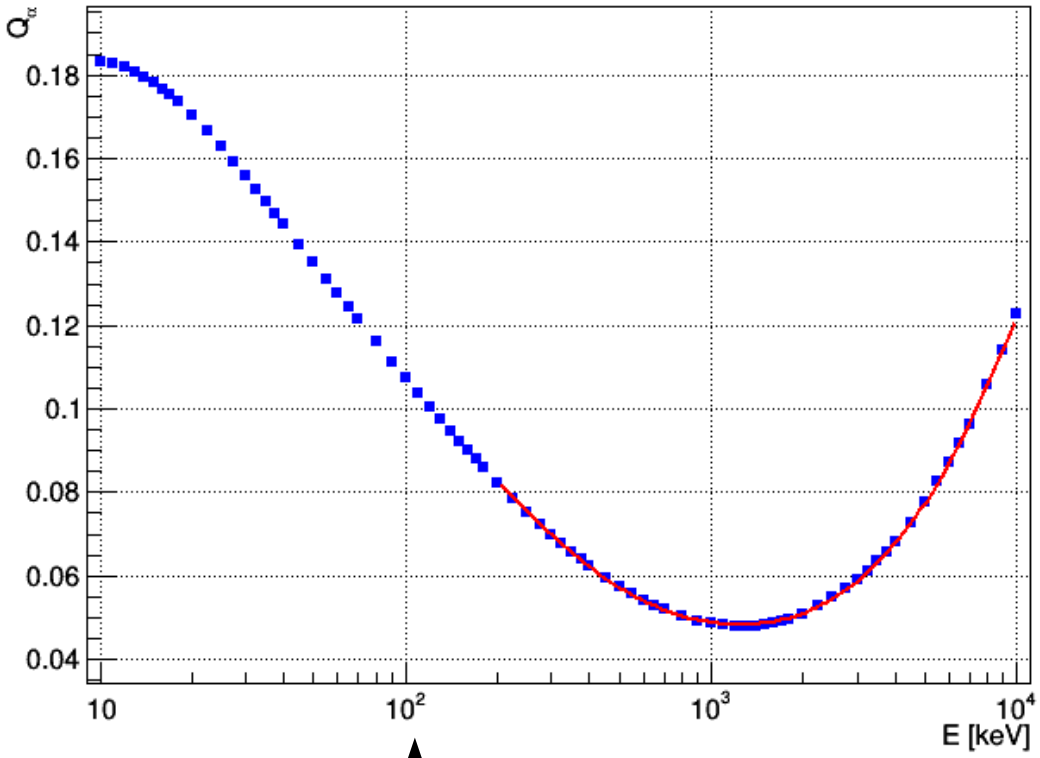
AGREED ACTIVITY FOR JUNO RADIOACTIVITY MONTE CARLO VALIDATION

Each group developing MC codes for JUNO background evaluation should run the same set of simulations for a comparison of the results under the same conditions.

STEP 1.a

* Geometry: JUNO acrylic sphere (Ø 35.4 m) filled with LAB
* 1E5 parent decays of 232Th, 238U, 210Pb and 40K
* Contaminated volume: all LAB
* Detecting volume: all LAB (no fiducial volume cut)
* No energy resolution applied
* Alpha quenching applied
* Energy range of output spectra: [0, 14 MeV], 10 keV/bin
* Correlated times: 1 ps to simulate no-correlated-time
* Total event rate: 1 Hz
* The surrounding universe is water

Quenching Factor in LAB



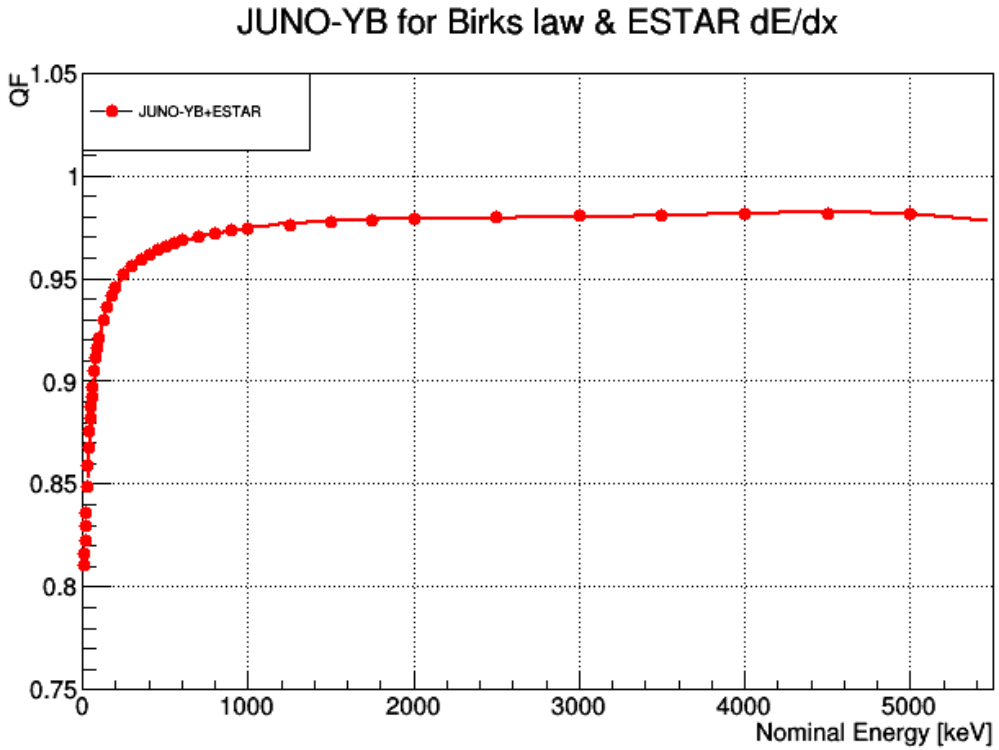
$$Q(E) = E/\int_0^E \frac{dE}{1 + C_1\delta + C_2\delta^2}.$$

$$\delta = \frac{dE}{\rho dx} \quad \mathrm{MeVg^{-1}cm^2}$$

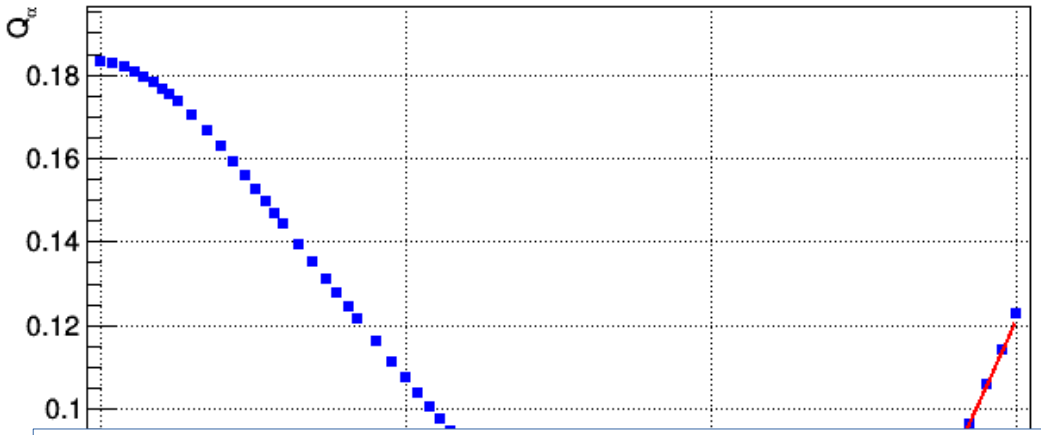
$C_1 = 6.5\times10^{-3}$ g/cm^2/MeV
$C_2 = 1.5\times10^{-6}$ (g/cm^2/MeV)^2

Alpha quenching:
- Birks coefficients from YB
- dE/dx from SRIM code

Electron quenching:
- Birks coefficients from YB
- dE/dx from ESTAR code



Quenching Factor in LAB



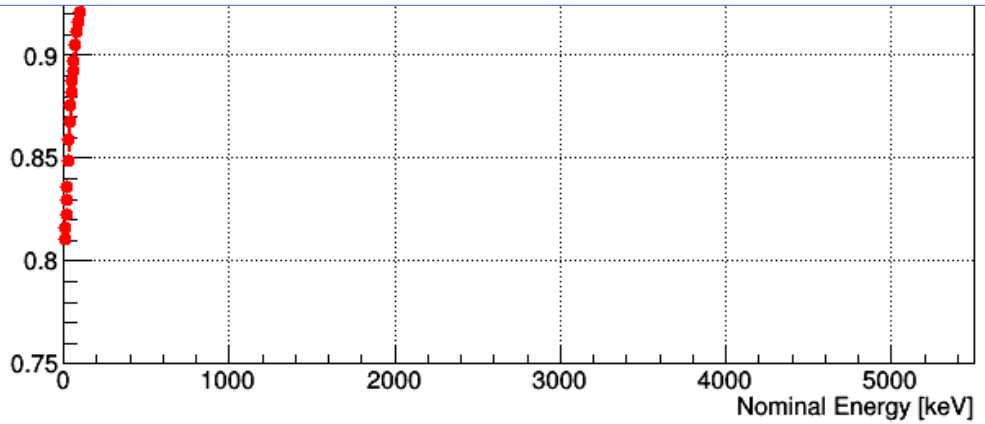
$$Q(E) = E / \int_0^E \frac{dE}{1 + C_1\delta + C_2\delta^2}.$$

$$\delta = \frac{dE}{\quad} \quad \mathrm{MeVg^{-1}cm^2}$$

We have implemented in Arby the QF calculation during the particle travel within the medium using these interpolation functions.

Electron quenching:

- Birks coefficients from YB
- dE/dx from ESTAR code



In the next slides all simulations are done with:

1 ps correlated time:

simulated parent decays: 1×10^5

and the following version of Geant4: g4.10.04.p02

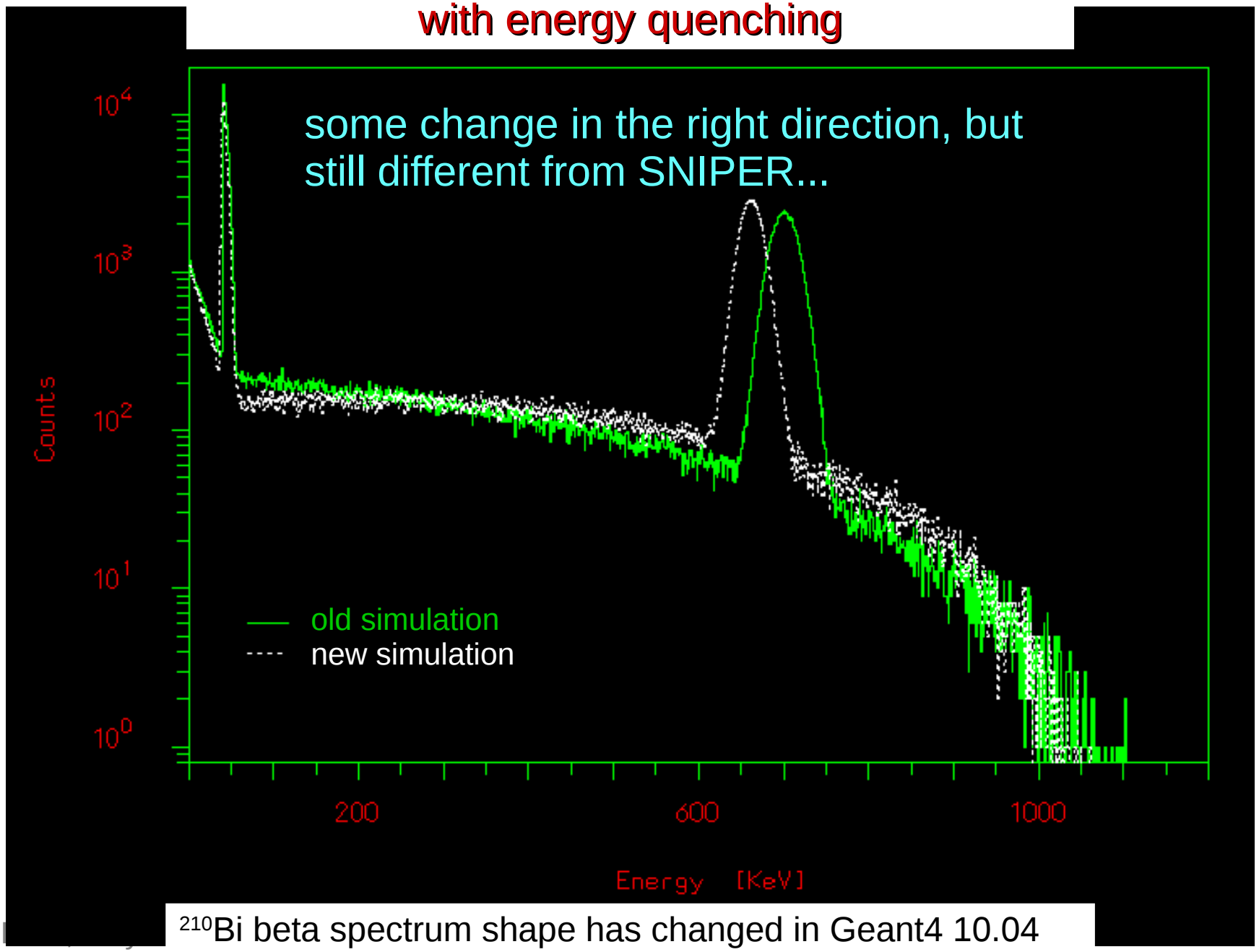
STEP 1.a

(unless otherwise stated...)

Old simulation: Geant4 g4.9.6.p03, QF calculated at the end
New simulation: Geant4 g4.10.04.p02, QF calculated step-by-step

Arby simulation: ^{210}Pb in whole LAB with quenching

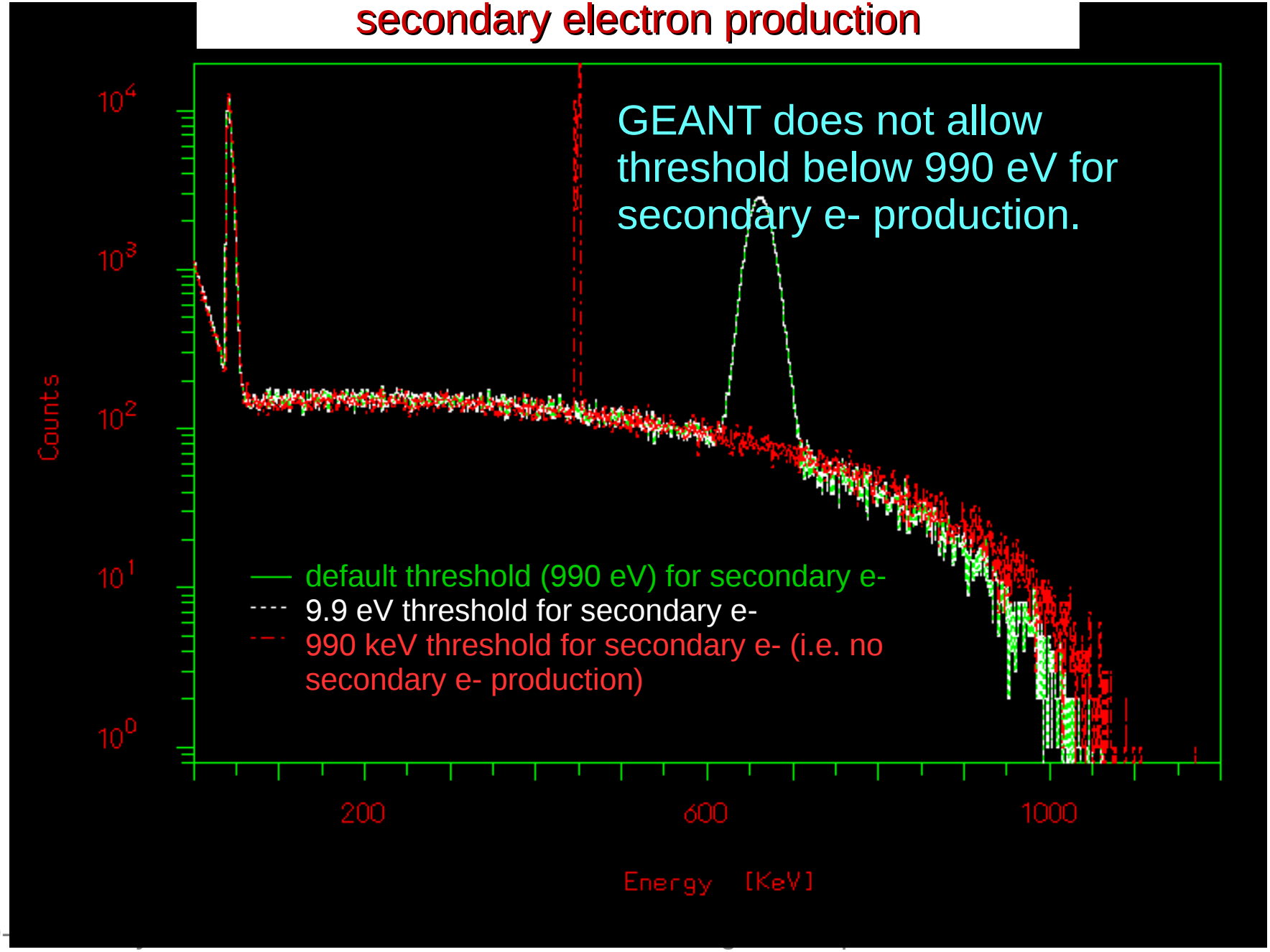
Comparison between old and new simulation with energy quenching



^{210}Bi beta spectrum shape has changed in Geant4 10.04

Arby simulation: ^{210}Pb in whole LAB with quenching

New simulation: changing the threshold for secondary electron production



Arby simulation: ^{210}Pb in whole LAB with quenching

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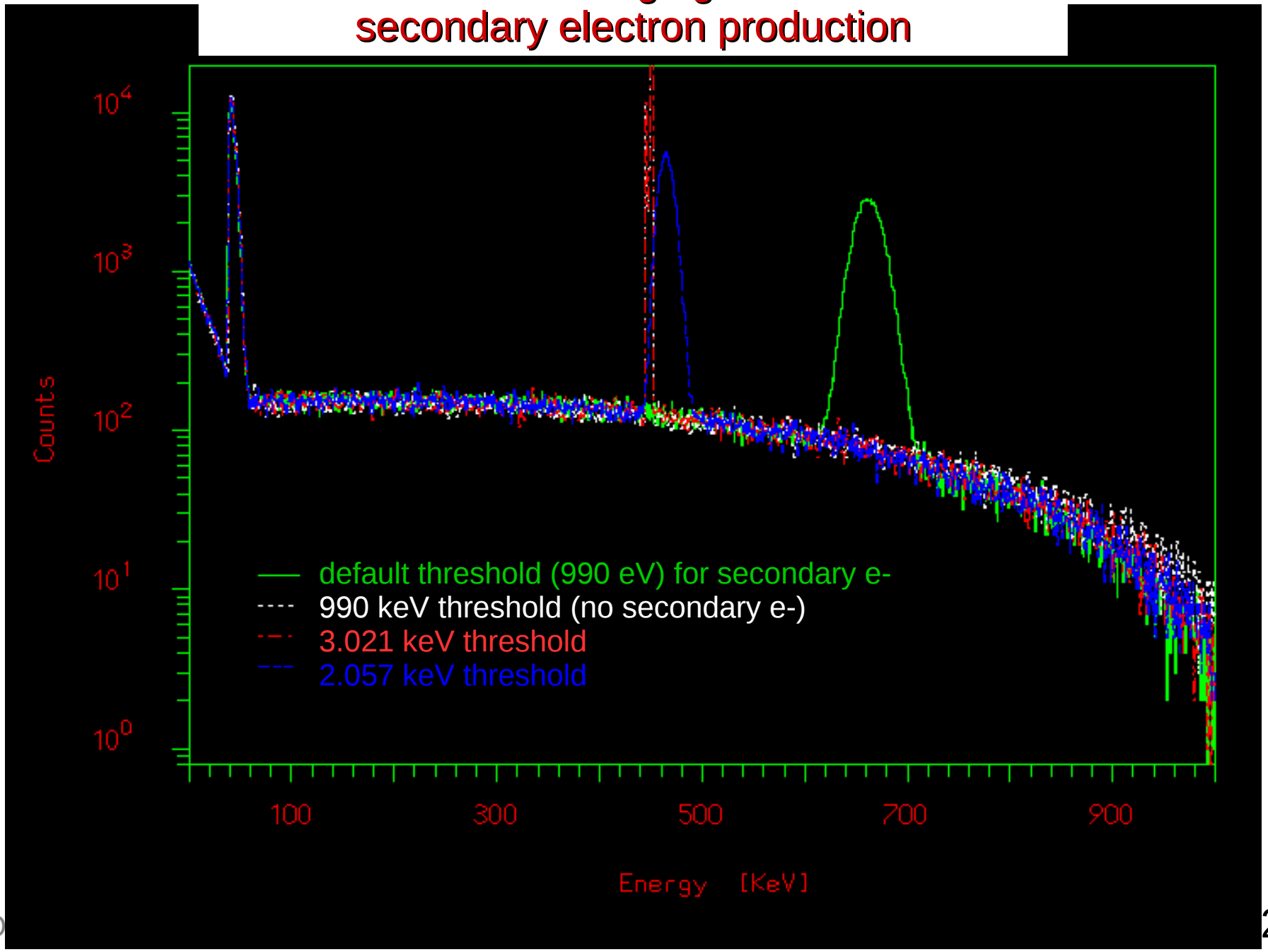
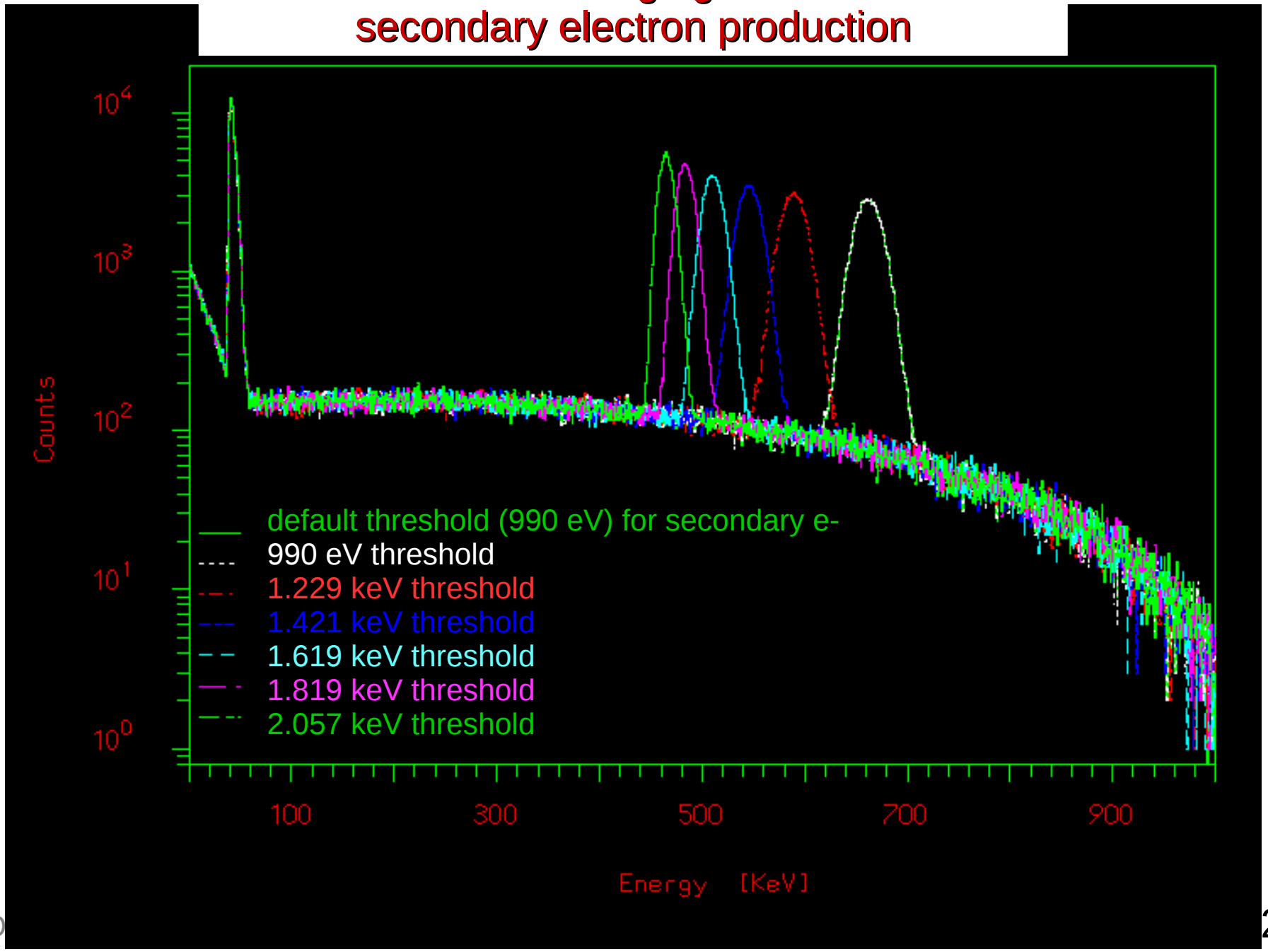


Arby simulation: ^{210}Pb in whole LAB with quenching

New simulation: changing the threshold for secondary electron production



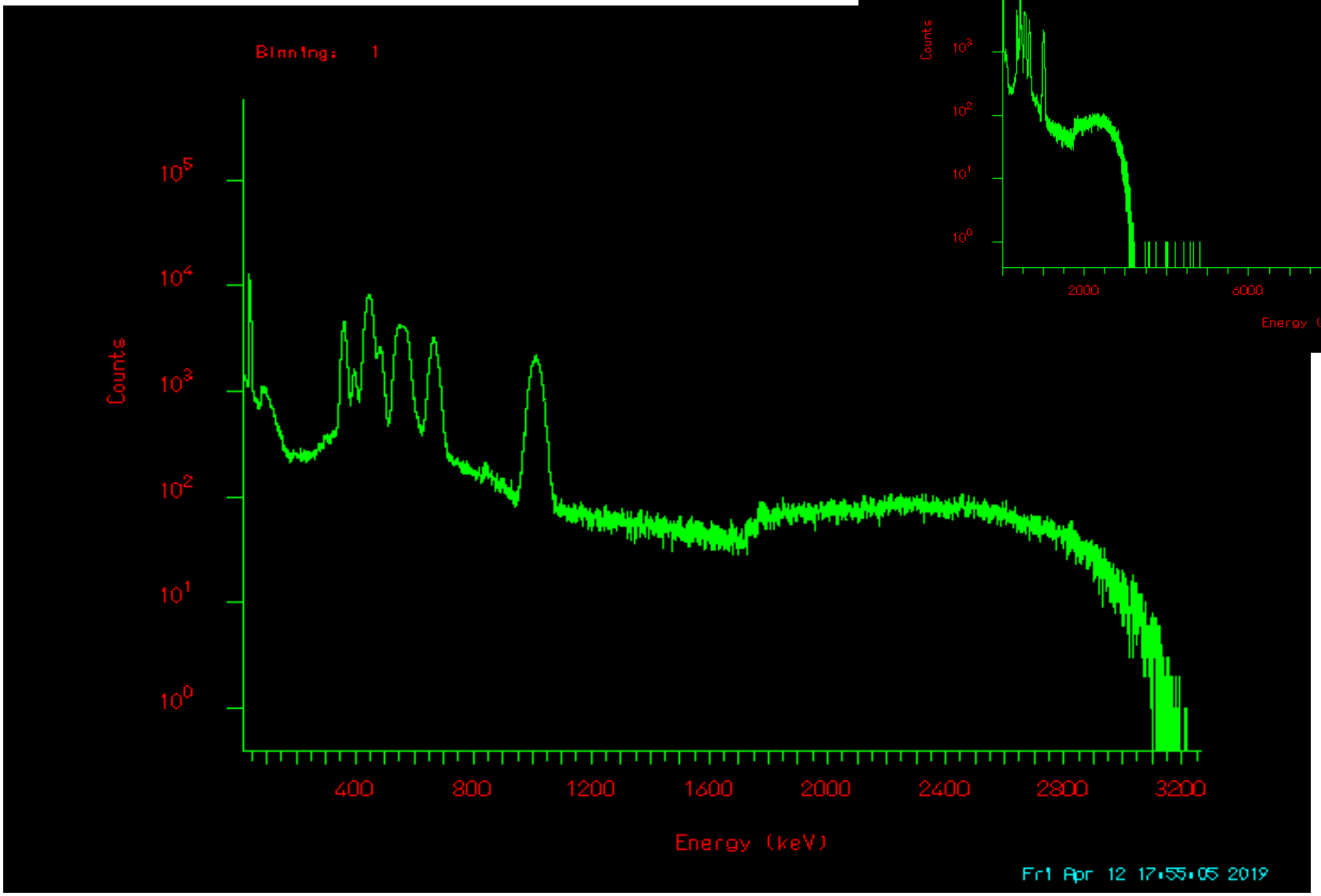
Arby simulation: ^{210}Pb in whole LAB with quenching

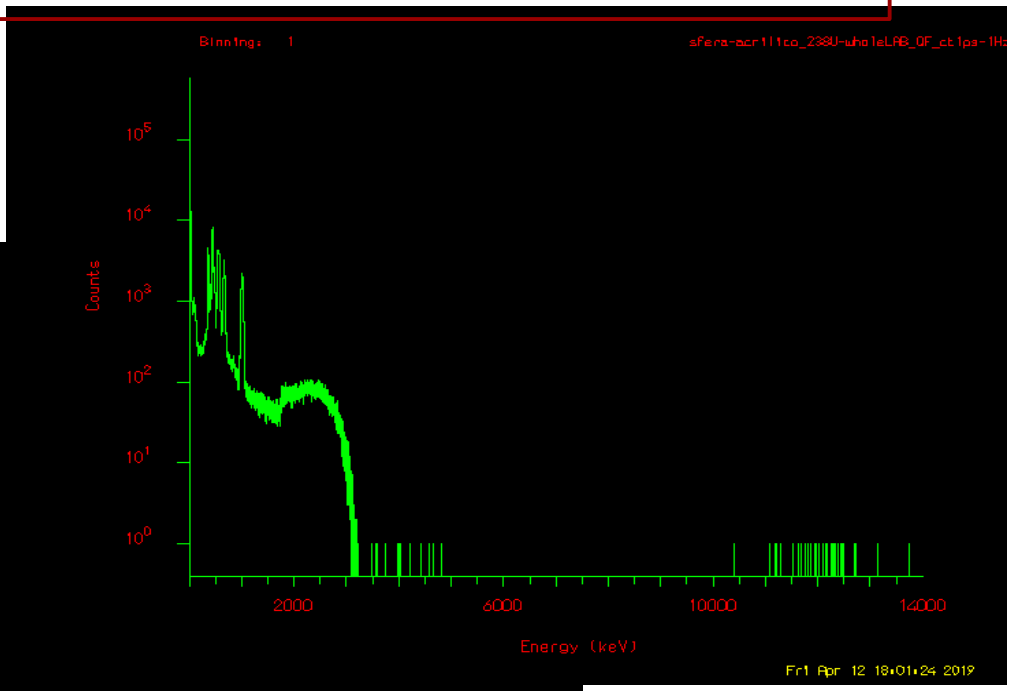
Isotope	MC NO-QUENCHING Q_value (keV)	MC NO-QUENCHING Alpha (keV)	MC QUENCHING Q_value (keV)	MC QUENCHING DE (keV)	MC QUENCHING quenching	MC QUENCHING Alpha (keV)	CALCULATED Q_value (keV)	CALCULATED Alpha (keV)	Opz -j in Arby
210Pb-chain									
210Po	5407		662	34	12.2%		440.7072		not specified
210Po	5407		662	34	12.2%		440.7072		-j 0.01
210Po	5407		662	34	12.2%		440.7072		-j 1
210Po	5407		662	34	12.2%		440.7072		-j 2
210Po	5407		662	34	12.2%		440.7072		-j 2.5
210Po	5407		589	31	10.9%		440.7072		-j 3
210Po	5407		546	28	10.1%		440.7072		-j 3.25
210Po	5407		510	24	9.4%		440.7072		-j 3.5
210Po	5407		484	20	8.9%		440.7072		-j 3.75
210Po	5407		465	18	8.6%		440.7072		-j 4
210Po	5407		451	4*	8.3%		440.7072		-j 5
210Po	5407		451	4*	8.3%		440.7072		-j 7
210Po	5407		451	4*	8.3%		440.7072		-j 10
210Po	5407		451	4*	8.3%		440.7072		-j 50
210Po	5407		451	4*	8.3%		440.7072		-j 100

*not a gaussian peak but a sharp one

The threshold for secondary electron production that makes the ^{210}Po peak position matching SNIPER ^{210}Po peak position is 1.421 keV

Arby simulation: ^{238}U in whole LAB with quenching and secondary e- threshold = 1.421 keV





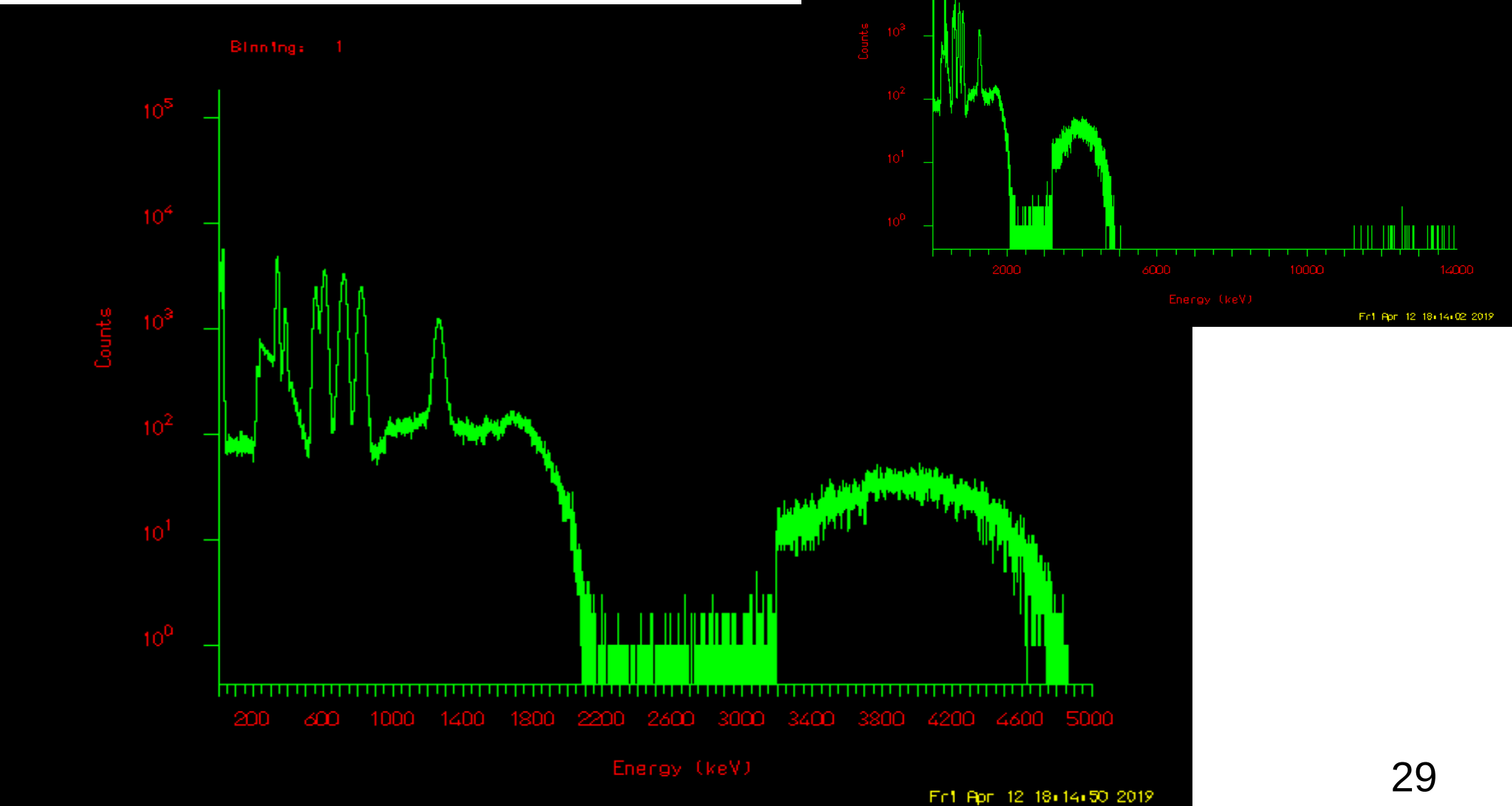
Arby simulation: ^{238}U in whole LAB with quenching and secondary e- threshold = 1.421 keV

Isotope	Nominal Energy Q_value (keV)	Nominal Energy Alpha (keV)	MC QUENCHING -j 3.25 Q_value (keV)	MC QUENCHING -j 3.25 DE (keV)	MC QUENCHING -j 3.25 quenching
U-chain					
238U	4270	4151	362	18	8.7%
238U		4198			
234U	4860	4722	447	28	9.5%
234U		4775			
230Th	4770	4620	397	15	8.6%
230Th		4687			
226Ra	4871	4784	485	23	10.1%
226Ra		4601			
222Rn	5590	5489	573	28	10.4%
218Po	6115	6002	667	33	11.1%
214Po	7833	7687	1012	46	13.2%
210Po	5407	5304	547	28	10.3%

SNIPER simulation results

isotope	No quenching	quenching		
isotope	Q _value/KeV	Q _value/KeV	quenching	FWHM
U238	4270	374	8.8%	12.4
U234	4859	463	9.5%	22.7
Th230	4770	408	8.6%	17.5
Ra226	4871	491	10.1%	23.6
Rn222	5590	581	10.4%	17.9
Po218	6115	674	11.0%	16.9
Po214	7830	1022	13.1%	20.9
Po210	5407	548	10.1%	14.9

Arby simulation: ^{232}Th in whole LAB with quenching and secondary e- threshold = 1.421 keV



Arby simulation: ^{232}Th in whole LAB with quenching and secondary e- threshold = 1.421 keV

	MC NO-QUENCHING		MC QUENCHING		
Isotope	Q_value (keV)	Alpha (keV)	Q_value (keV)	DE (keV)	quenching
Th-chain					
232Th	4083		338	16	8.3%
228Th	5521		385	16	7.0%
224Ra	5788		558	32	9.6%
220Rn	6405		718	36	11.2%
216Po	6907		819	40	11.9%
212Bi	6208		609	32	9.8%
212Po	8955		1263	55	14.1%

SNIPER simulation results

isotope	No quenching	quenching		
isotope	Q _value/KeV	Q _value/KeV	quenching	FWHM
Th232	4083	347	8.5%	12.5
Th228	5520	389	7.0%	20.2
Ra224	5789	569	9.8%	14
Rn220	6405	726	11.3%	20.3
Po216	6906	827	12.0%	17.9
Bi212	6207	616	9.9%	16.3
Po212	8954	1265	14.1%	25.5

CONCLUSIONS

Finally SNIPER and Arby results match!!!

Good news BUT:
To obtain this I had to change the threshold for secondary electron production in Geant to 1.4 keV.
What about this parameter in SNIPER?
There is no obvious reason to me to have this threshold higher than the default one (990 eV). So why this?

Additional info:
We use Geant **without** scintillation option: I guess that is not the same in SNIPER. Could it be that some parameters set for the scintillation option influence the secondary particles threshold? Is it possible to know which parameters are changed from default value in SNIPER?

THE SAGA GOES ON...

Arby simulation: ^{238}U in whole LAB with quenching and secondary e- threshold = 1.421 keV