Foil source optimisation study

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Introduction

- Different foil design are under discussion
- The optimal foil source should allow to:
  - Reach the **best sensitivity**
  - Produce as **less background** as possible
- Recently started a study to optimise the foil design
  - Different foil design implemented in the *legacy* software
  - Produce samples of: **0nu**, **2nu**, **208Tl**, **214Bi**
- Compare foil design: **energy distribution**, **detection efficiency**, **sensitivity**

These are just QUALITATIVE results…

…and will raise more questions than answer

Which material density?

NIST database adopted by Geant4

	Se	PVA	Nylon	Mylar
g/cm3	4.5	1.19	1.14	1.4

The density of a mix is given by the mass fraction of the different components

$$\rho = \sum_i f_i \times \rho_i \qquad \text{[g\cm3]}$$

The surface density is

$$a = \sum_i a_i \qquad \text{[g\cm2]}$$

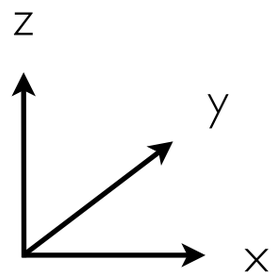
Then the foil thickness is obtained

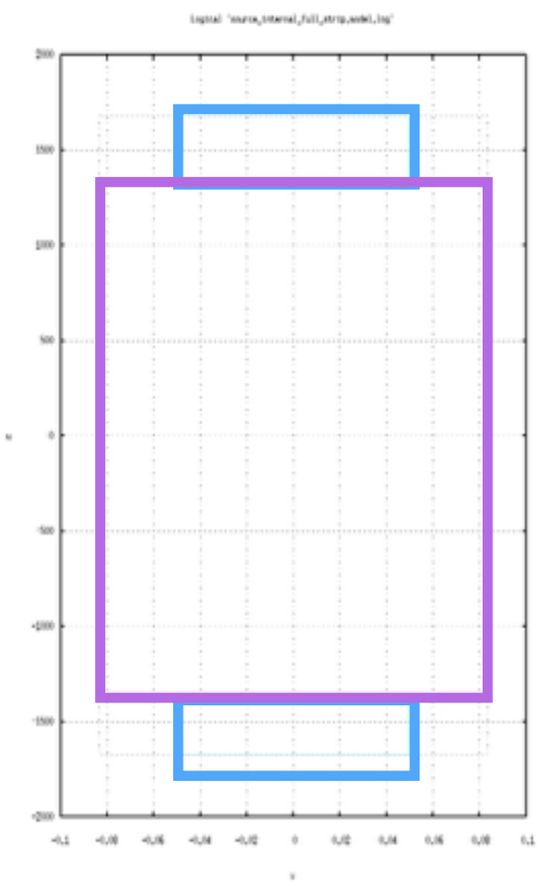
$$t = \frac{a}{\rho}$$

Ideal foil design (default in legacy)

Just Se + PVA, no mechanical support…

From NEMO3 numbers (i.e. legacy code configuration)





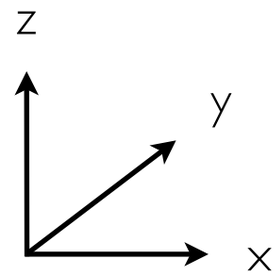
	g/cm3	mg/cm2	M fraction	Thickness [um]
Se	???	47.5	0.95	
PVA	1.19	2.5	0.05	
Foil source	3	50.0	1	167

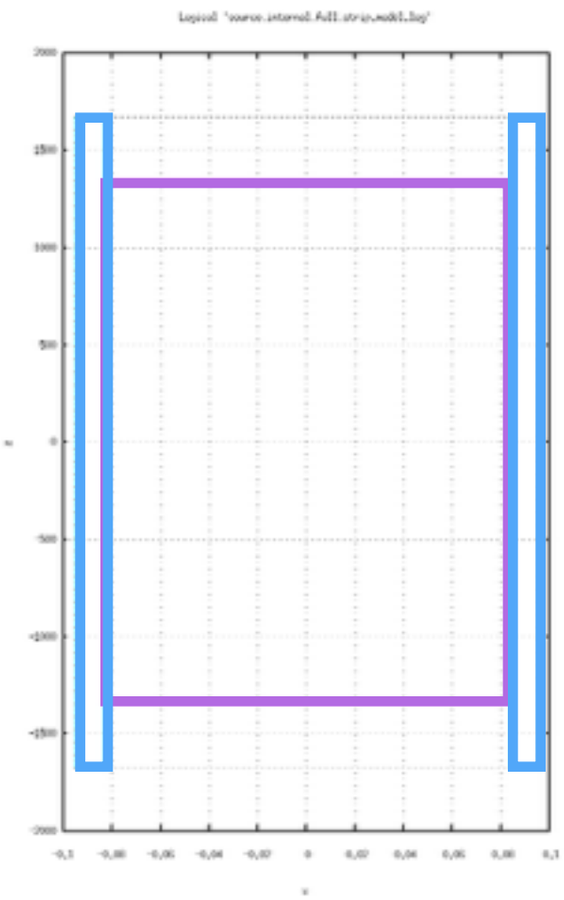
Not sure on that parameter (I would expect ~4 g/cm3…)

Need to clarify the Se density adopted.
I assume 3 g/cm3 in the follow in order to get consistent results

Backing film design (ITEP proposal)

Same as before, but add mylar backing film



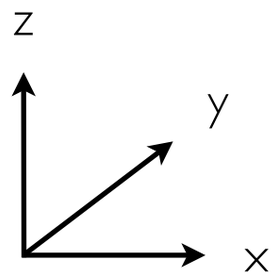


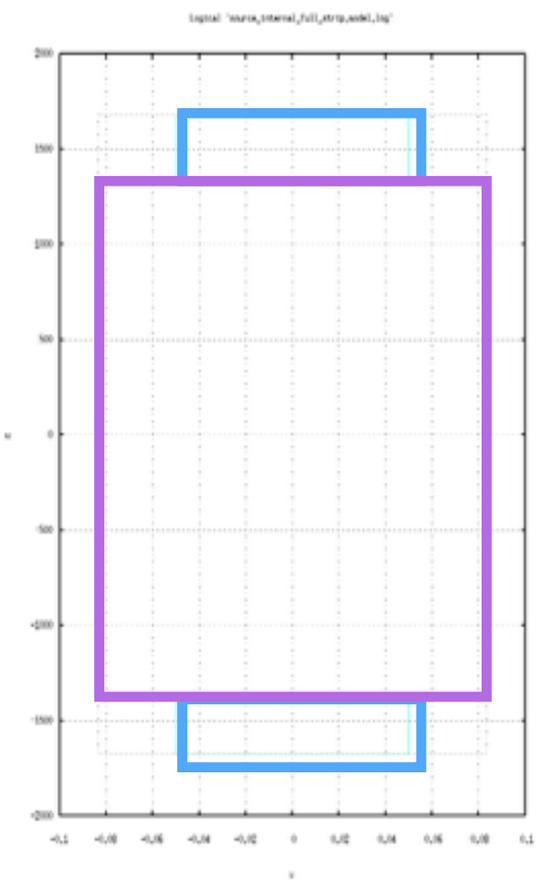
	g/cm3	mg/cm2	M fraction	Thickness [um]
Se	???	47.5	0.866	
PVA	1.19	2.5	0.045	
Backing film	1.4	5.0	0.089	12
Foil source	3	56.0	1	191

Tulle design (LAPP proposal)

For simulation purpose:

- Tulle (nylon) is homogeneous mixed in the foil





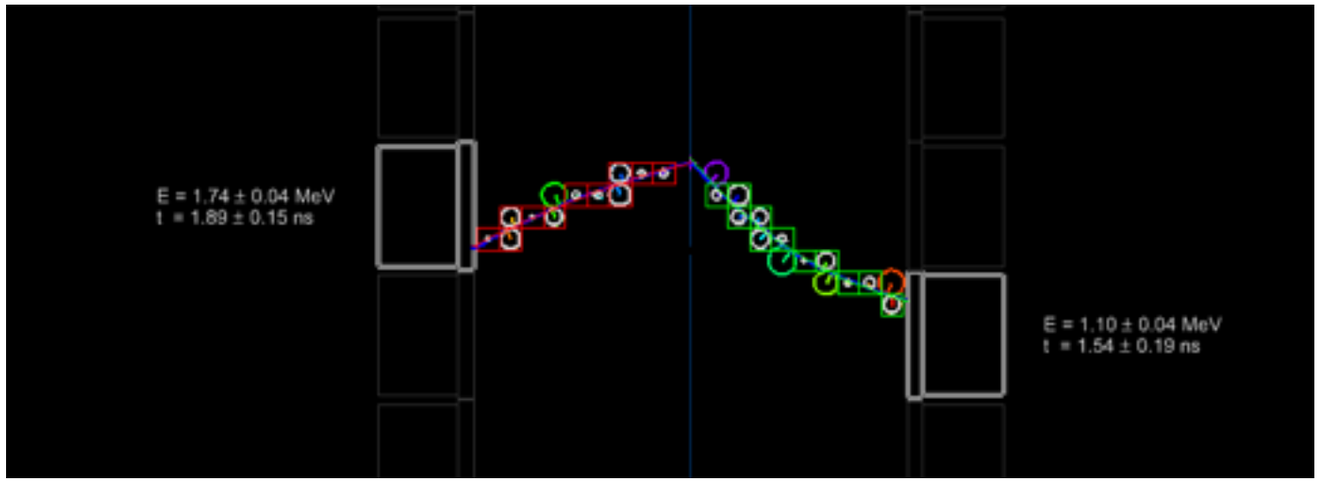
	g/cm3	mg/cm2	Mass fraction	Thickness [um]
Se	???	50	0.94 (0.898)	
PVA	1.19	2.5 (5.0)	0.05 (0.09)	
Nylon	1.14	0.7	0.01 (0.012)	
Foil source	2.98	53.2 (55.7)	1	178 (187)

Thinner foil w.r.t. mylar solution

Room to increase fraction of PVA ==> better foil resistance (but, depend on radio purity…)

Event generation

- Event generation & reconstruction based on DocDB 2424 (X. Garrido)
- Simulate detector response (Legacy code)
- Event reconstruction (snanalysis chain)
  - Basic tracker clustering
  - Track fit with line or helix
- Dummy event selection



- 2 calo hit associated to 2 negative tracks + Vertex on foil

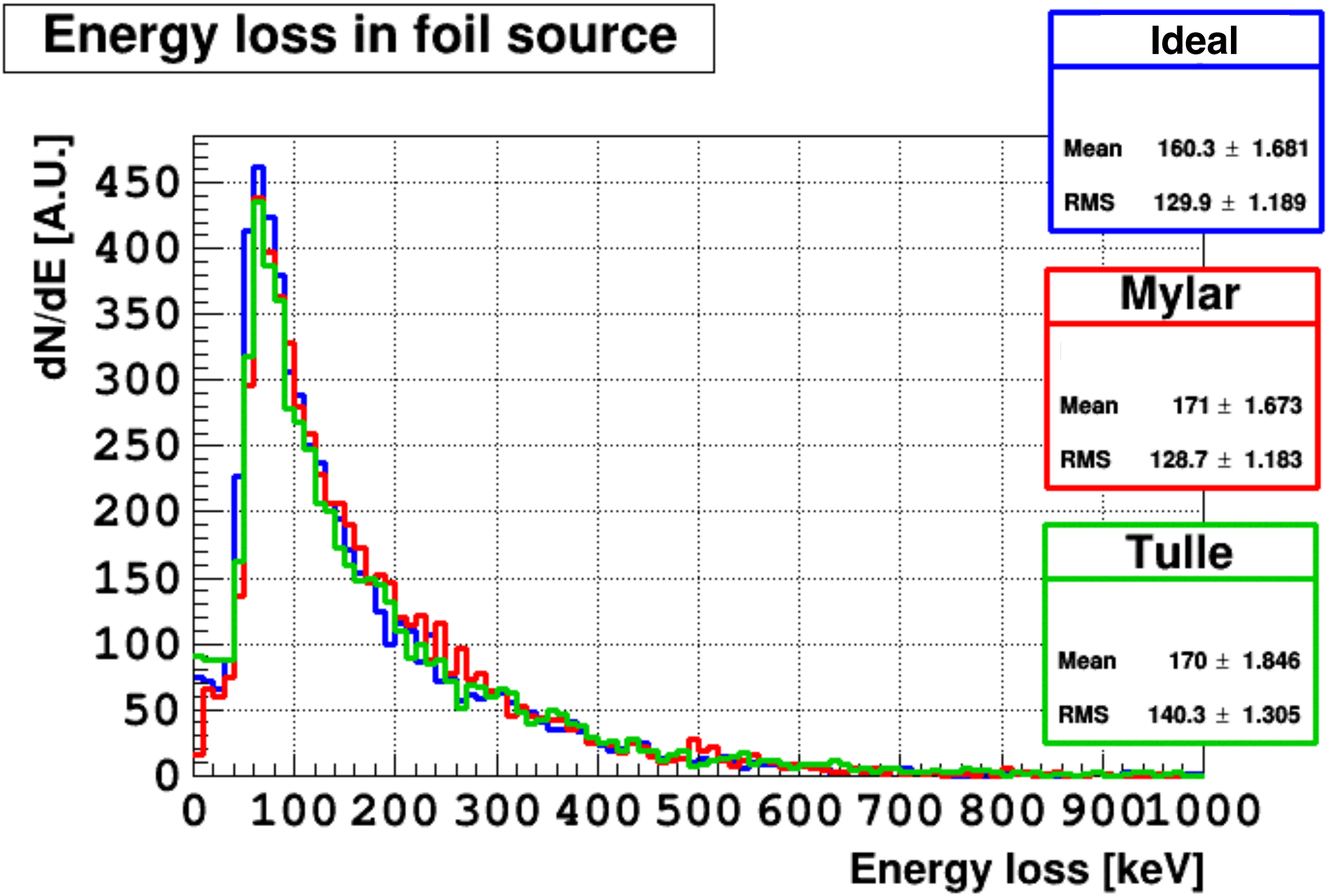
	bb0nu	**bb2nu**	**208Tl**	**214Bi**
Ideal	100k	1M	10M	10M
Tulle	100k	1M	10M	10M
Mylar	100k	1M	10M	10M

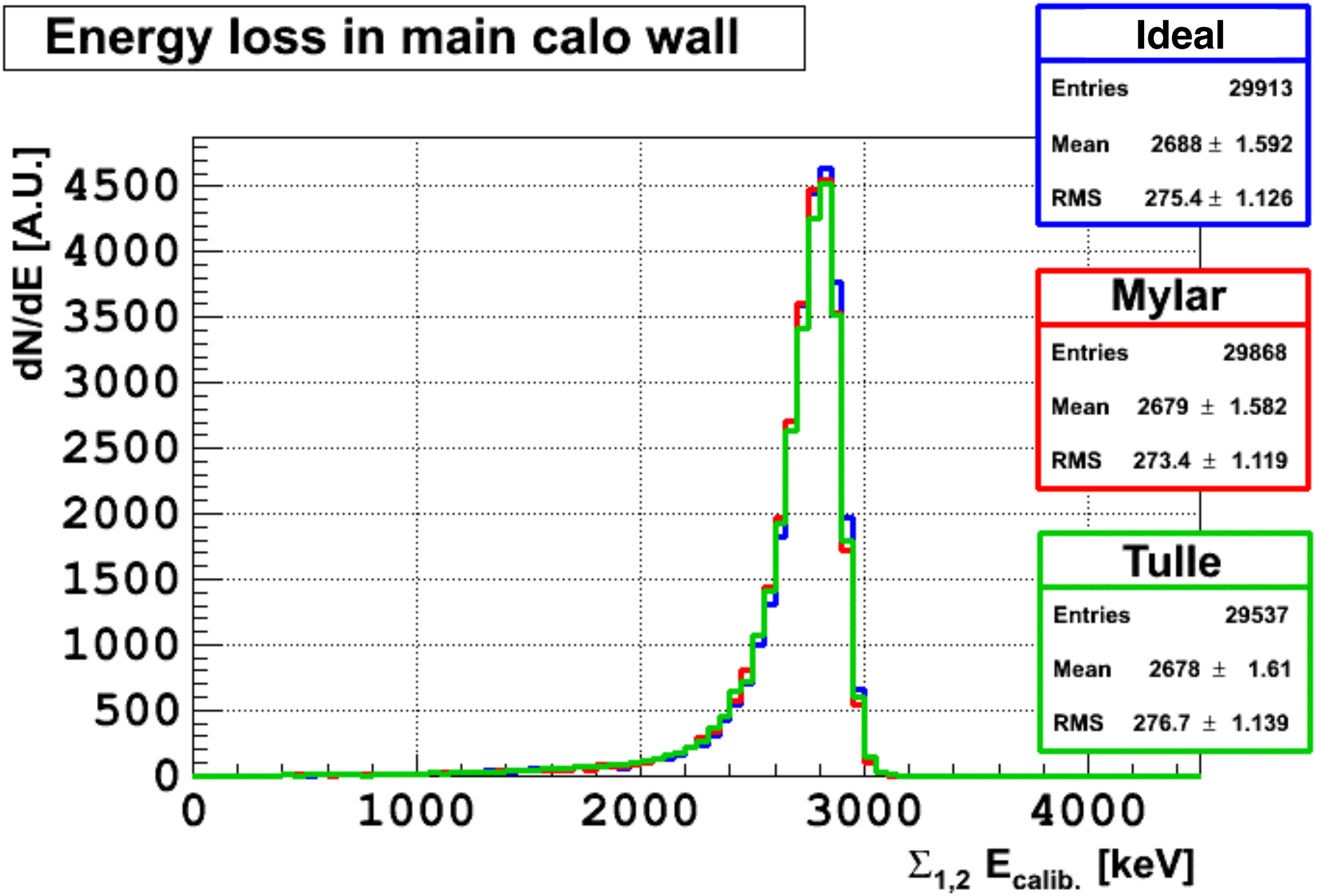
I don't care about details of event selection

just relative comparison among foils design is enough

bb0nu & bb2nu

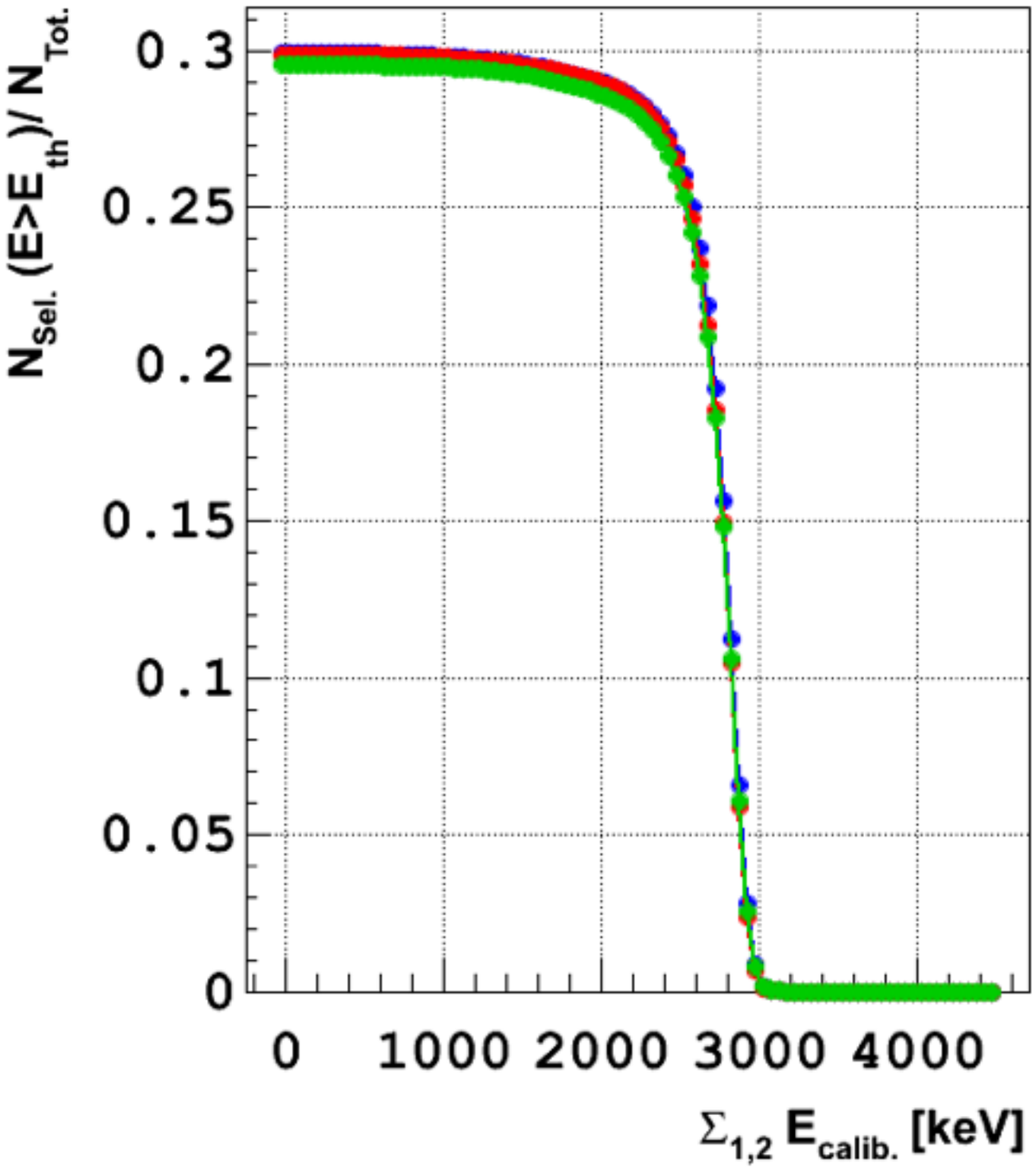
bb0nu


Energy loss in foil source
dN/dE [A.U.]
450
400
350
300
250
200
150
100
50
0
0 100 200 300 400 500 600 700 800 9001000
Energy loss [keV]
Ideal
Mean 160.3 ± 1.681
RMS 129.9 ± 1.189
Mylar
Mean 171 ± 1.673
RMS 128.7 ± 1.183
Tulle
Mean 170 ± 1.846
RMS 140.3 ± 1.305


Energy loss in main calo wall
dN/dE [A.U.]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
$\Sigma_{1,2}$ $E_{calib.}$ [keV]
Ideal
Entries 29913
Mean 2688 ± 1.592
RMS 275.4 ± 1.126
Mylar
Entries 29868
Mean 2679 ± 1.582
RMS 273.4 ± 1.119
Tulle
Entries 29537
Mean 2678 ± 1.61
RMS 276.7 ± 1.139

PRELIMINARY

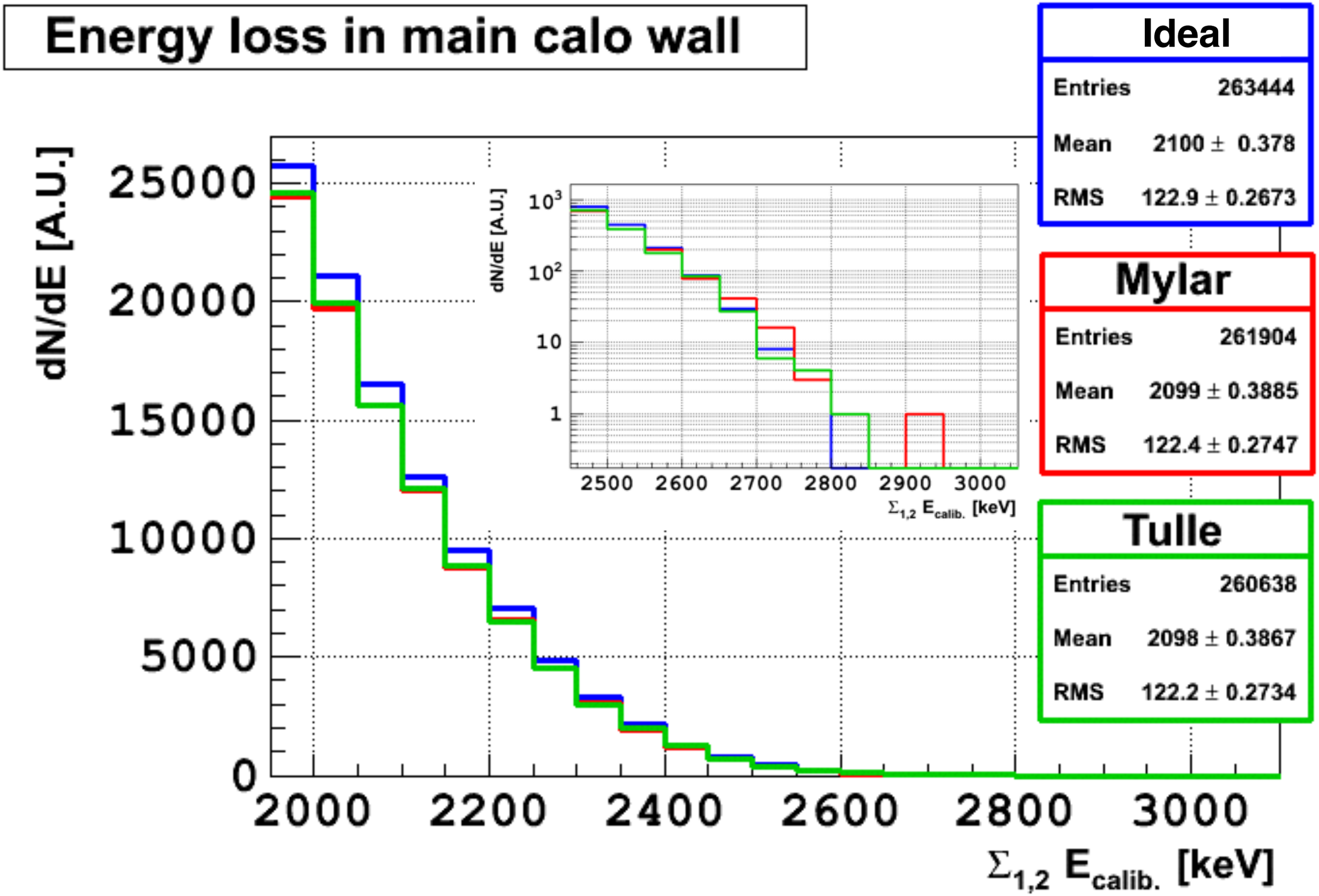
Absolute selection efficiency vs E_{th}



bb0nu selection efficiency

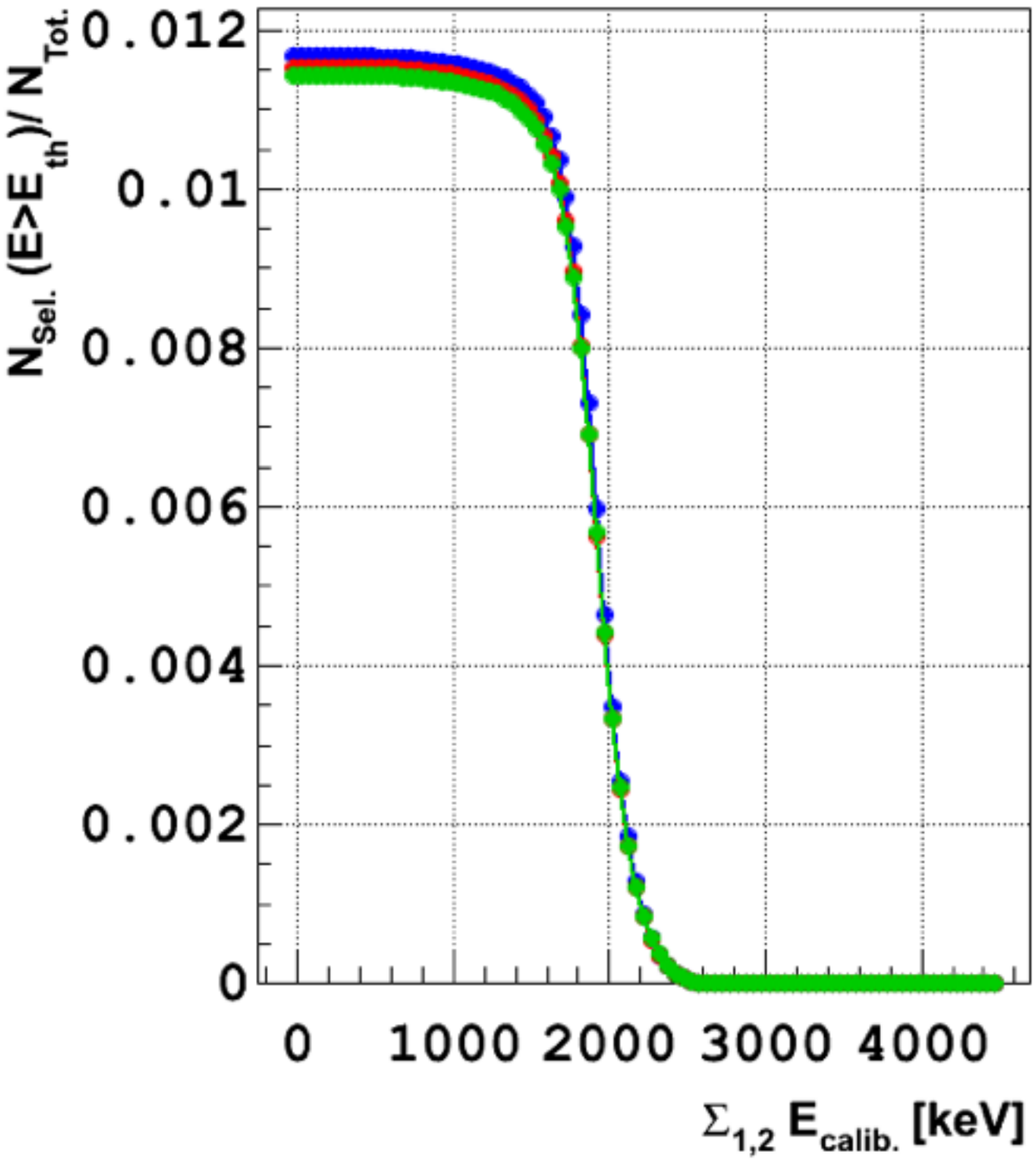
	Eff [%] [0; 4.0] MeV
Ideal	30
Tulle	29.5
Mylar	29.6

I do not have the detailed cut flow


Energy loss in main calo wall
dN/dE [A.U.]
25000
20000
15000
10000
5000
0
2000
2200
2400
2600
2800
3000
$\Sigma_{1,2}$ $E_{calib.}$ [keV]
dN/dE [A.U.]
10^3
10^2
10
1
2500
2600
2700
2800
2900
3000
$\Sigma_{1,2}$ $E_{calib.}$ [keV]
Ideal
Entries 263444
Mean 2100 ± 0.378
RMS 122.9 ± 0.2673
Mylar
Entries 261904
Mean 2099 ± 0.3885
RMS 122.4 ± 0.2747
Tulle
Entries 260638
Mean 2098 ± 0.3867
RMS 122.2 ± 0.2734

PRELIMINARY

Absolute selection efficiency vs E_{th}



bb2nu selection efficiency

	Eff [%] [0; 4.0] MeV
Ideal	~1.16
Tulle	~1.14
Mylar	~1.15

I do not have the detailed cut flow

GEANT4 issue

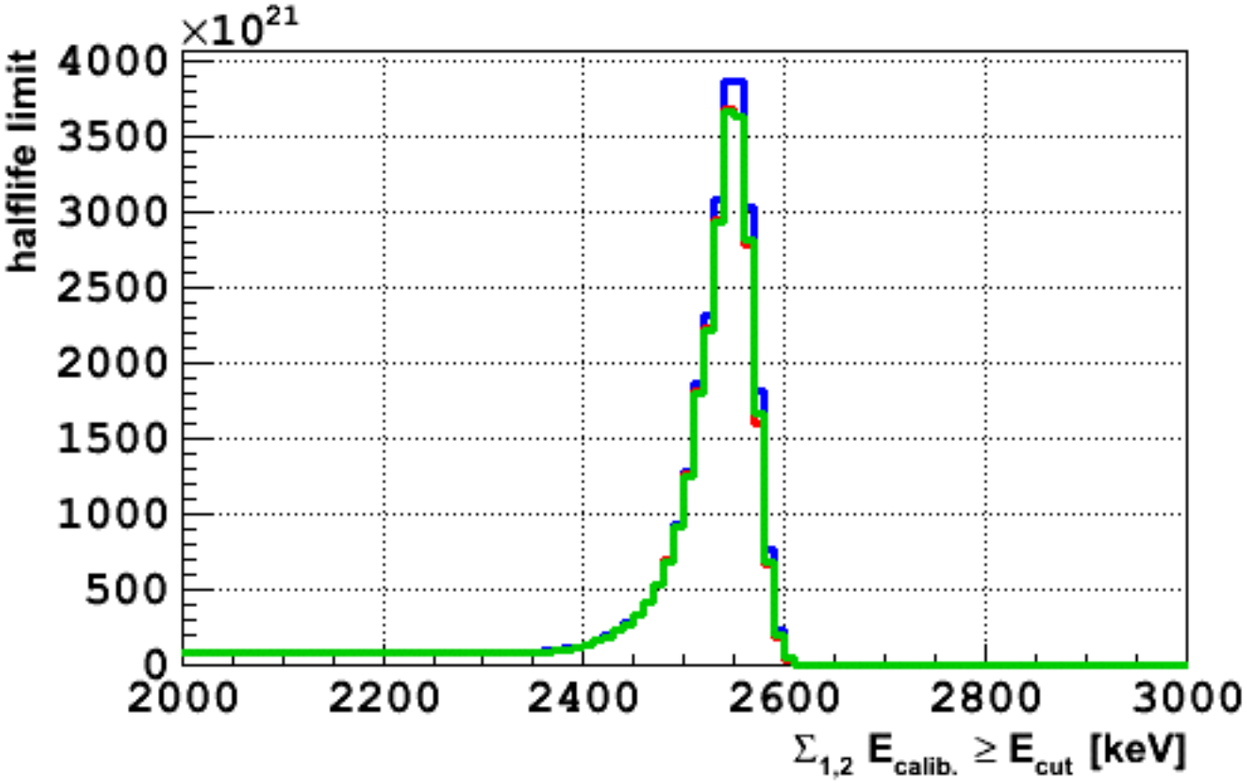
- **Different** GEANT4 version provide **different selection efficiency (!)**
- e. g. Pia presentation later
- e.g. Xavier G. DocDB 2424
- Same code is used ==> same event selection…
- Xavier & Francois is on the subject

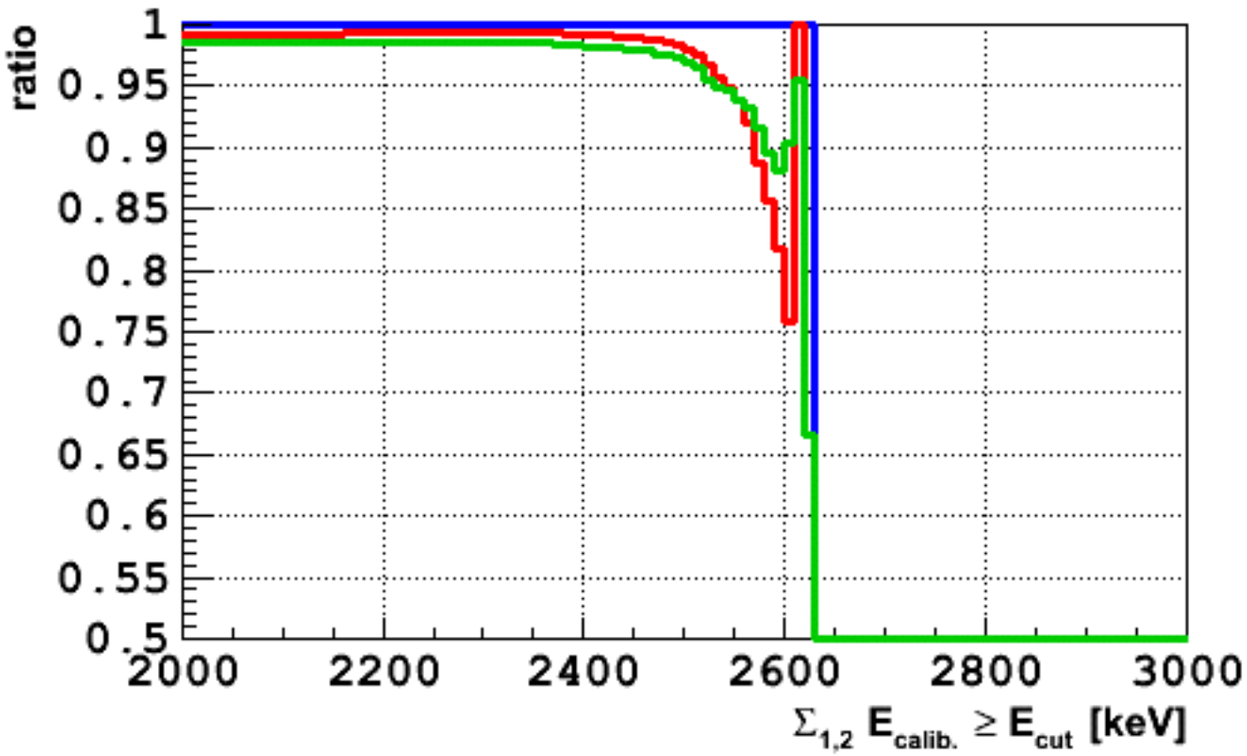
GEANT4 version	bb0nu Efficiency
9.5.b01	~20 %
9.6.p01	~30 %

- Issue seems to be due to multiple scattering
  - Less MS in newer version
  - More reco'ed electron track
  - Bigger efficiency
- Same effect on background…

Sensitivity

PRELIMINARY





$$T^{0\nu}_{1/2} > \frac{\log 2 N_A}{W} \times \epsilon^{0\nu} \frac{M \times T}{N_{\mathrm{EXC.}}}$$

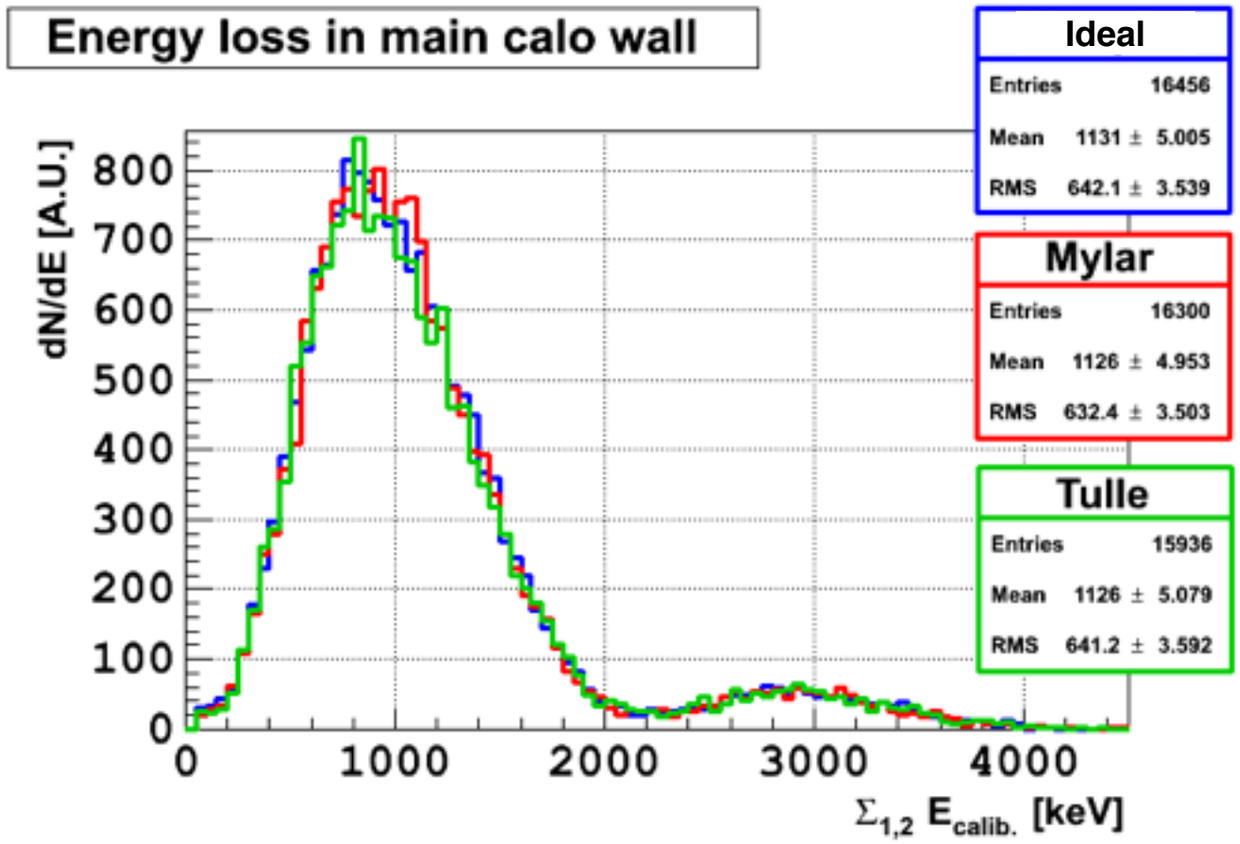
- Study performed as function of E_{cut}
- Signal ==> 0nu
- Background ==> 2nu
- Exposure ==> 7 kg x 2 y

	E_{cut} [keV]	Eff [%]	$T^{0nu}_{1/2}$ [10^{24} y]	r
Ideal	2550	25.5	3.88	1
Tulle	2550	24.8	3.66	0.943
Mylar	2550	25.2	3.67	0.946

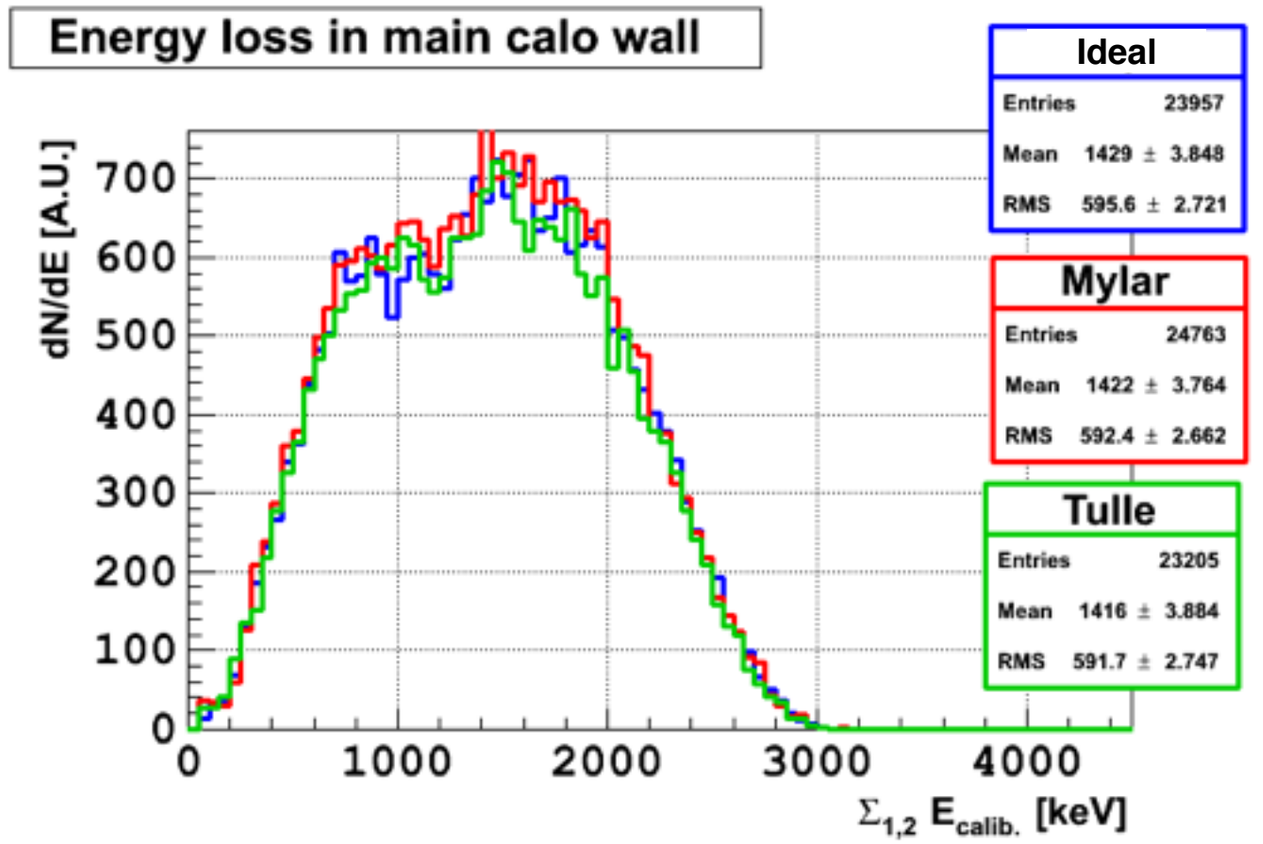
Need to x-check these numbers with independent calculations

Internal backgrounds

Background spectral shape

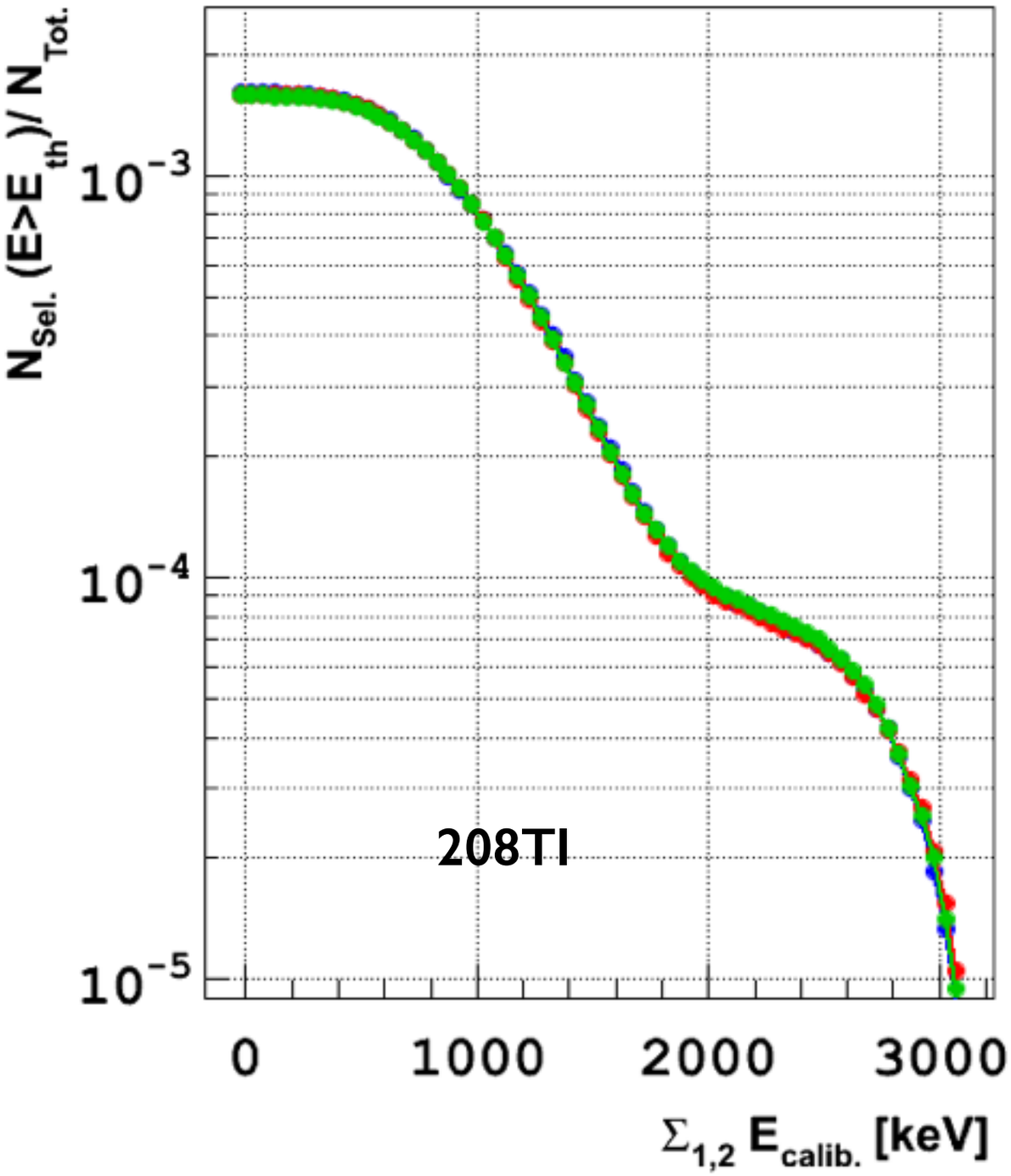


208TI

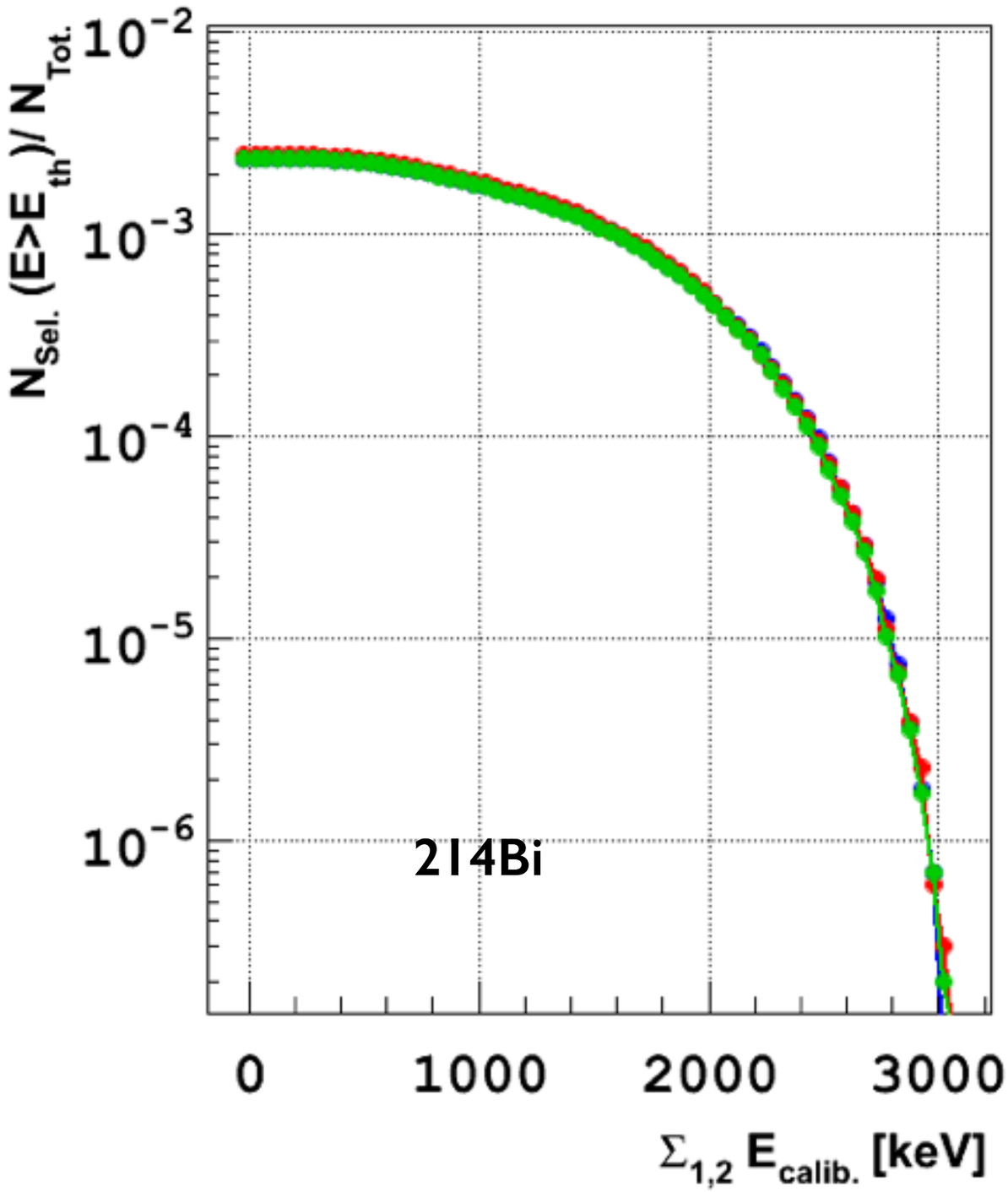


214Bi

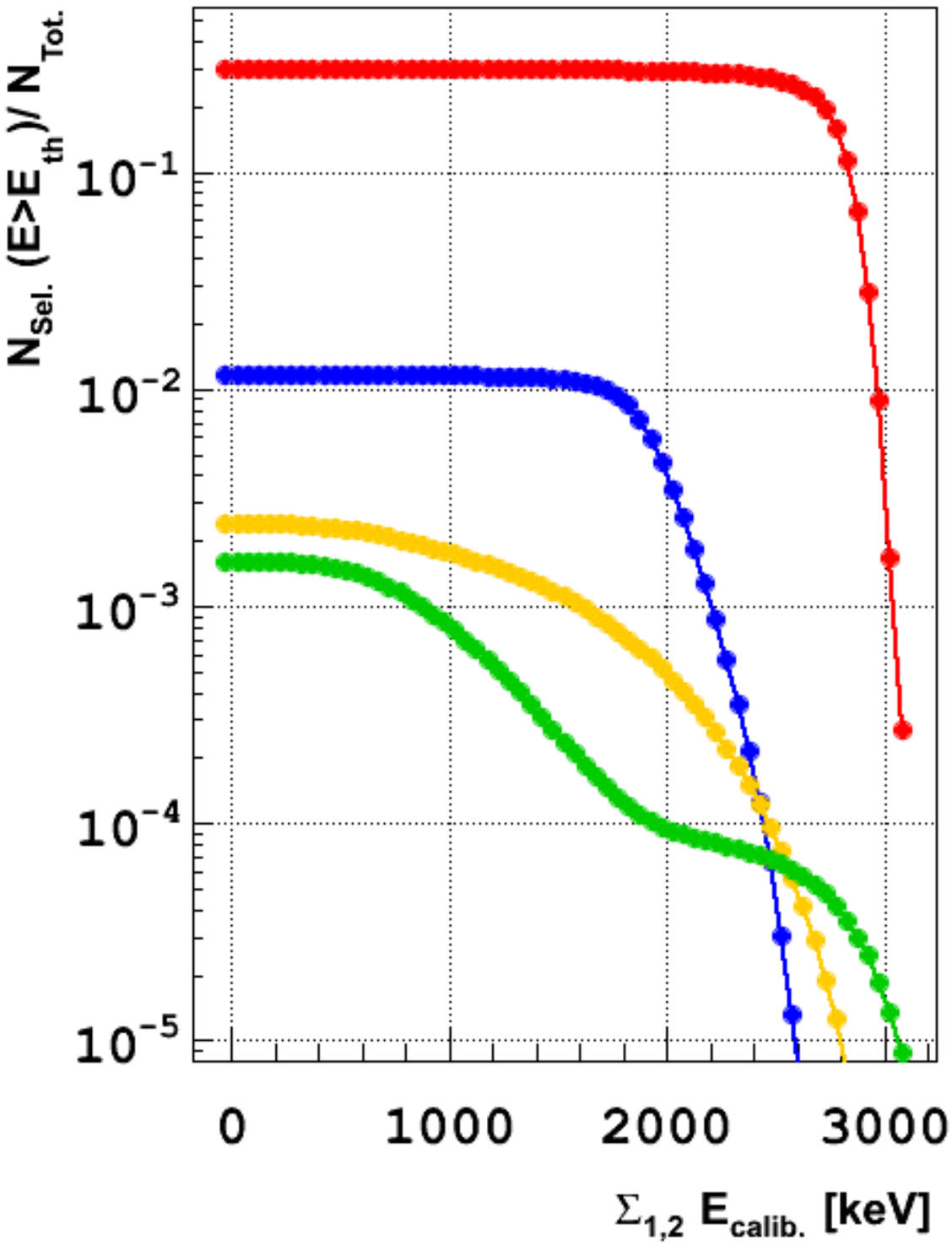
Absolute selection efficiency vs E_{th}



Absolute selection efficiency vs E_{th}



Absolute selection efficiency vs E_{th}



Selection efficiency for **ideal** foil design

	Eff [%]
bb0nu	30.0
bb2nu	1.15
214Bi	0.25
208Tl	0.16

I do not have the detailed cut flow

Background efficiency

PRELIMINARY

For the **ideal** foil design

	Eff in [2.5; 3.1] MeV [%]	Eff in [2.6; 3.1] MeV [%]	Eff in [2.7; 3.1] MeV [%]
bb0nu	25.8	15	10
bb2nu	0.45×10^{-2}	0.80×10^{-3}	0.01×10^{-3}
214Bi	0.75×10^{-2}	0.50×10^{-2}	0.25×10^{-2}
208Tl	0.65×10^{-2}	0.60×10^{-2}	0.50×10^{-2}

With the usual limits on internal background activity:

- Exposure of 7 kg x 2 y and [2.5; 3.1] MeV ROI:
- A(214Bi) = 10 uBq/kg ==> 0.3 background evt.
- A(208Tl) = 2 uBq/kg ==> 0.05 background evt.

Just a factor 2 among Tl & Bi efficiency: I was expecting a factor 5…

Conclusions

- Preliminary study to optimise foil source design
- Three design has been tested: **ideal**, **mylar** and **tulle**
- **Signal** and **background** (2nu, 208Tl, 214Bi) generated for each design
- **Mylar** and **Tulle** design has been found **compatible** as regards:
  - Electron energy loss (in foil and calo)
  - Detection efficiencies (against same signal selection)
  - Sensitivity (considering 0nu & 2 nu only)

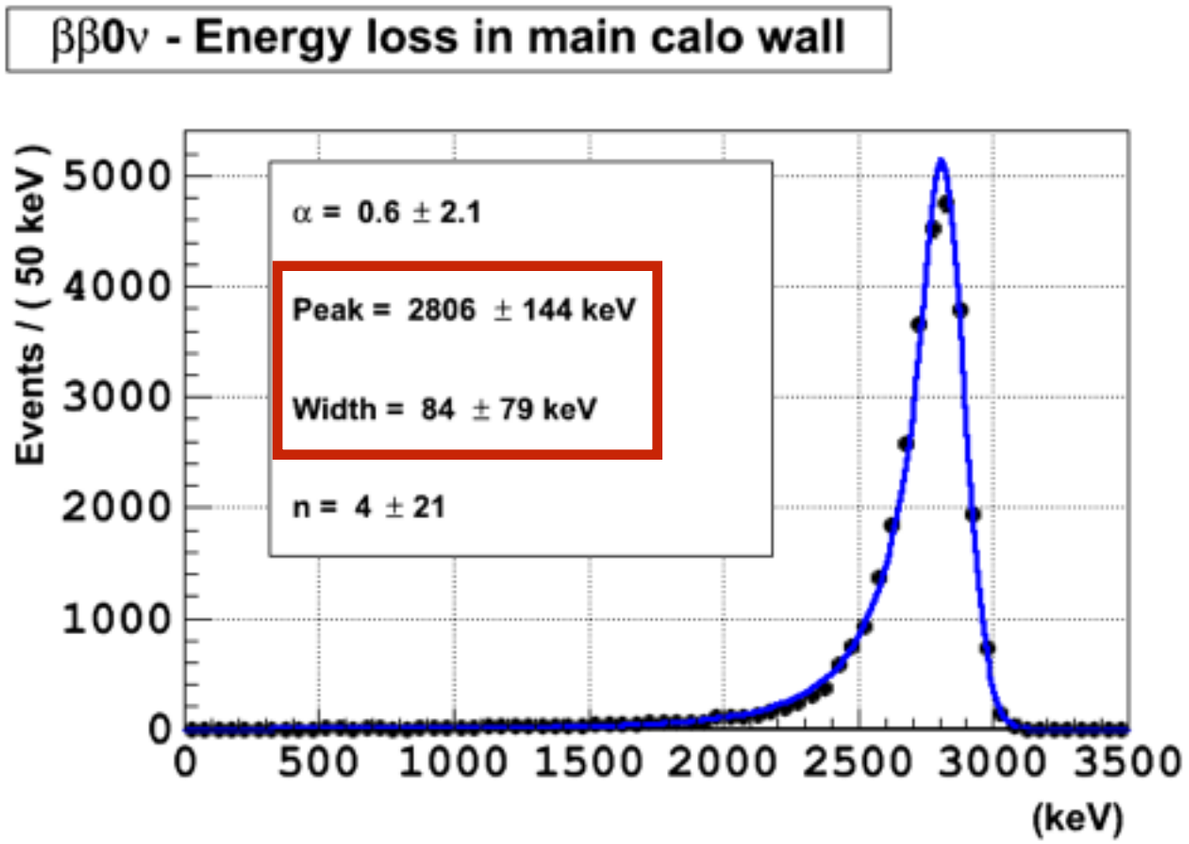
Next steps

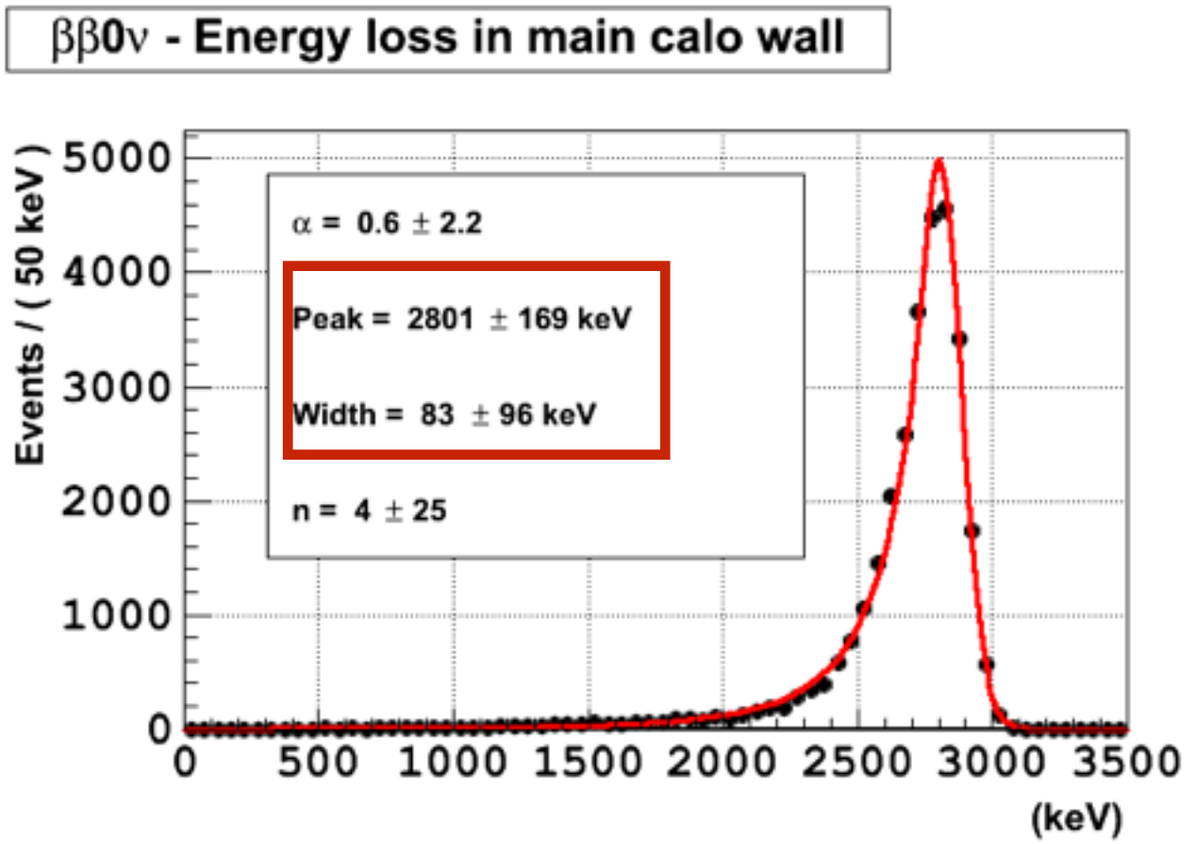
- There is a dependence on the GEANT4 version ➡ To be understood
- Factor 2 among TI and Bi efficiency (factor 5 is expected) ➡ To be understood
- Internal background need to be accounted in the sensitivity study
  - Cross check foil source radio-purity requirement

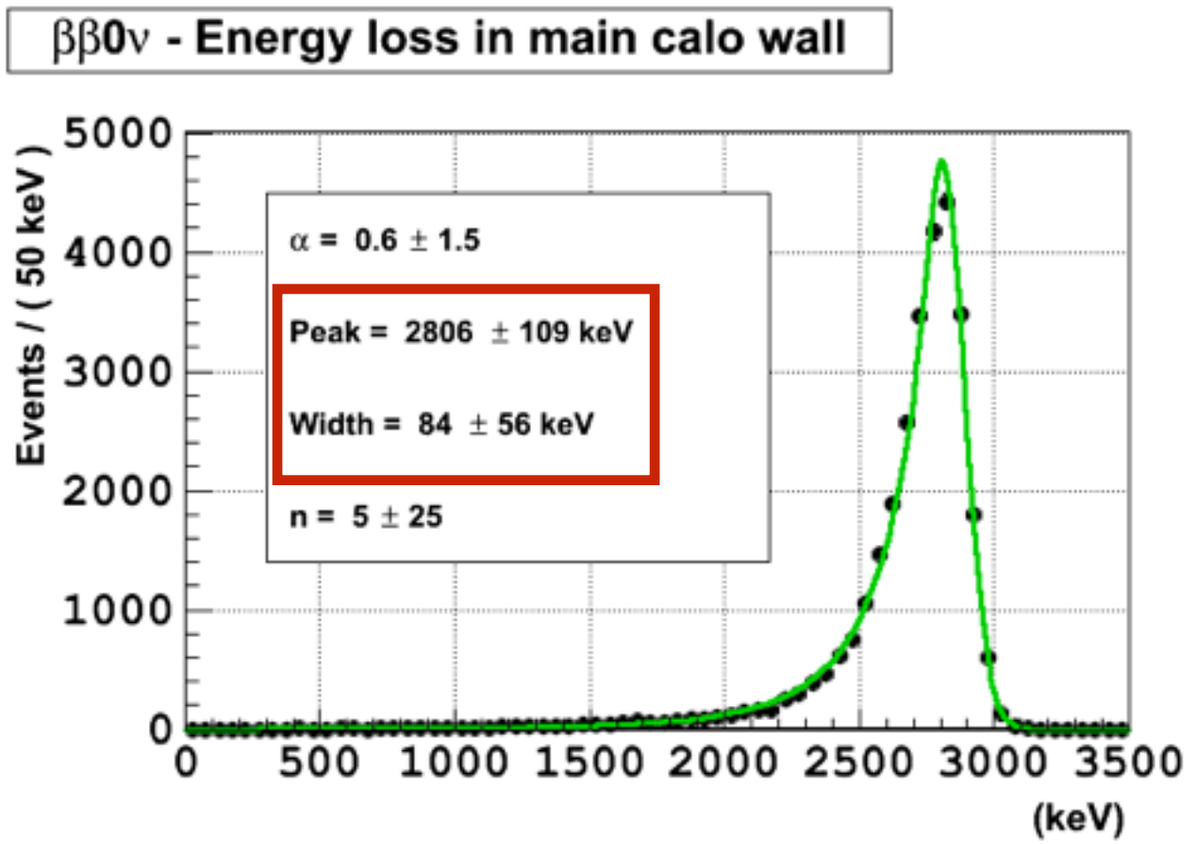
- SuperNEMO simulation is now available in the new Falaise trunk
- snanalysis code to be reviewed and ported in Falaise
- This study will be completed within the new framework

Backups

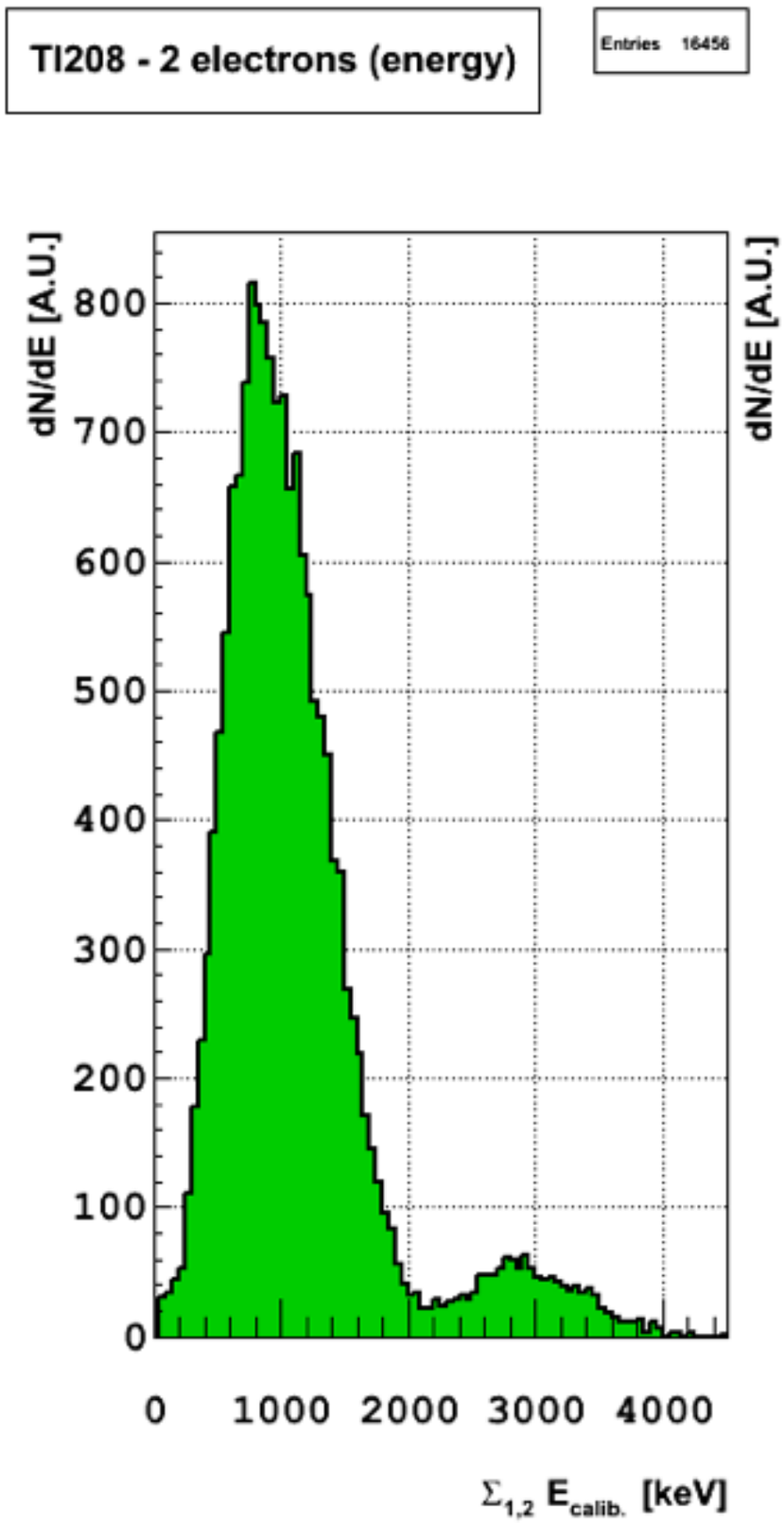
Comparison with a crystal ball fit

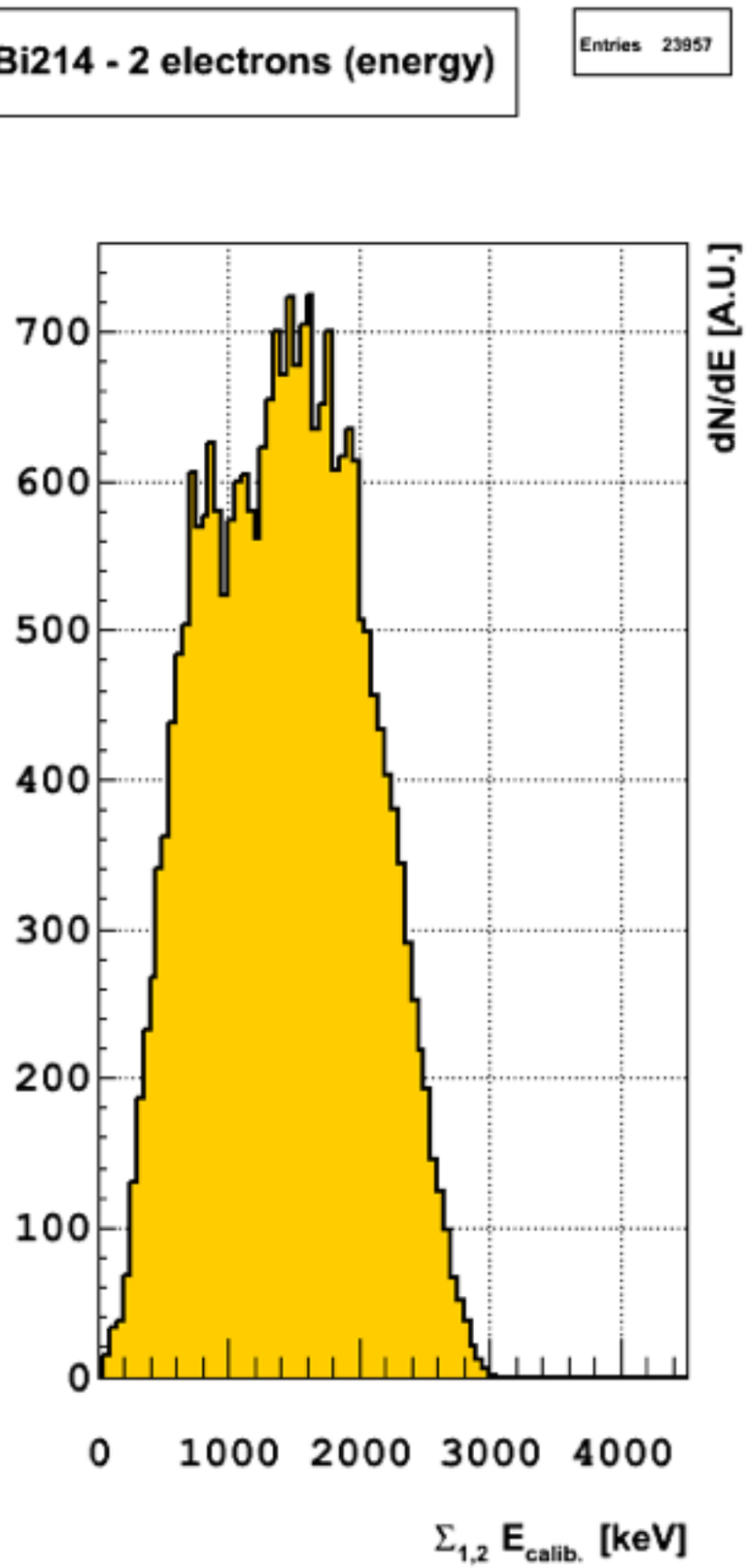


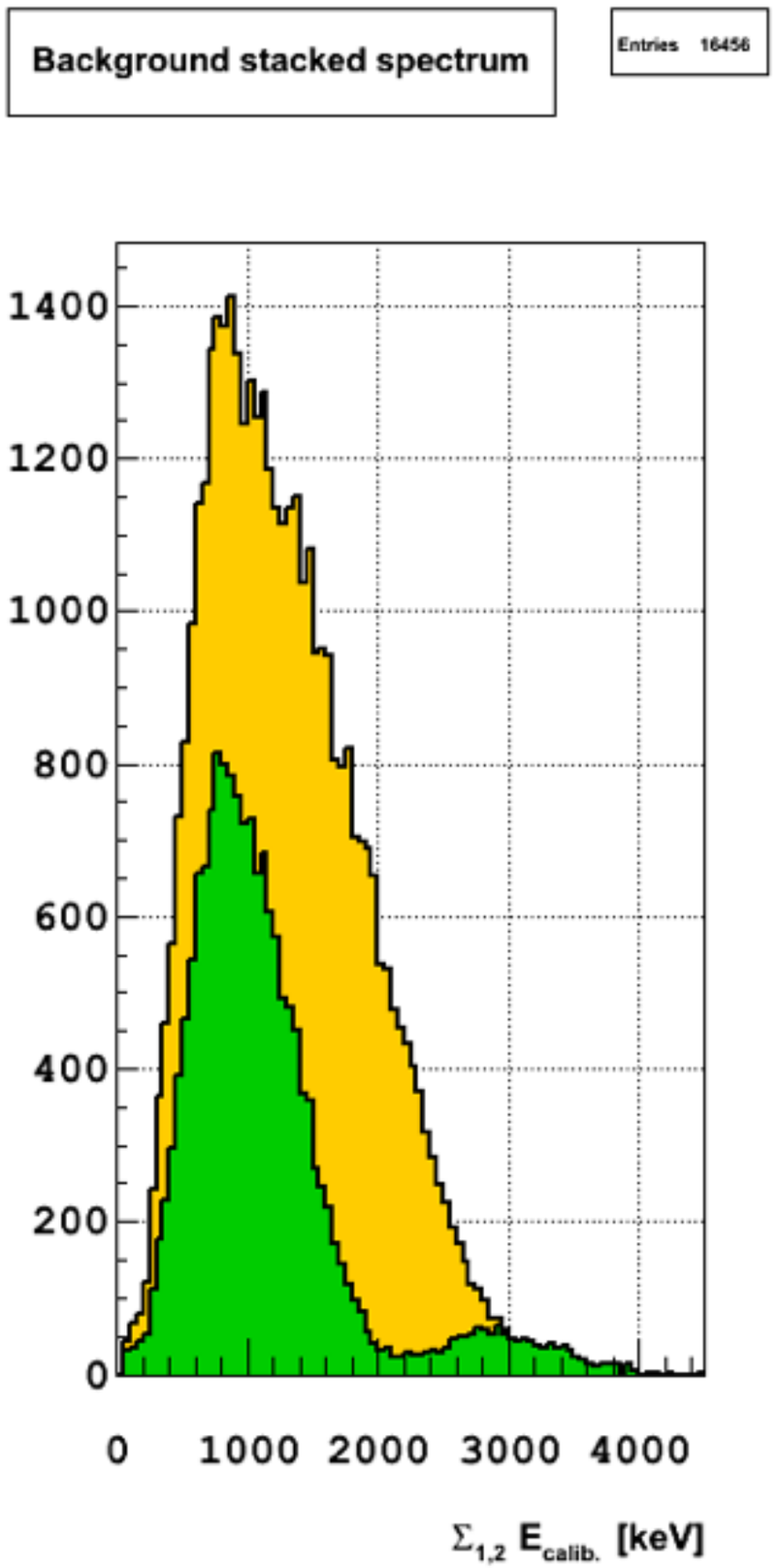




	chi²
Ideal	4.22
Mylar	4.27
Tulle	3.19







Same dummy selection as before