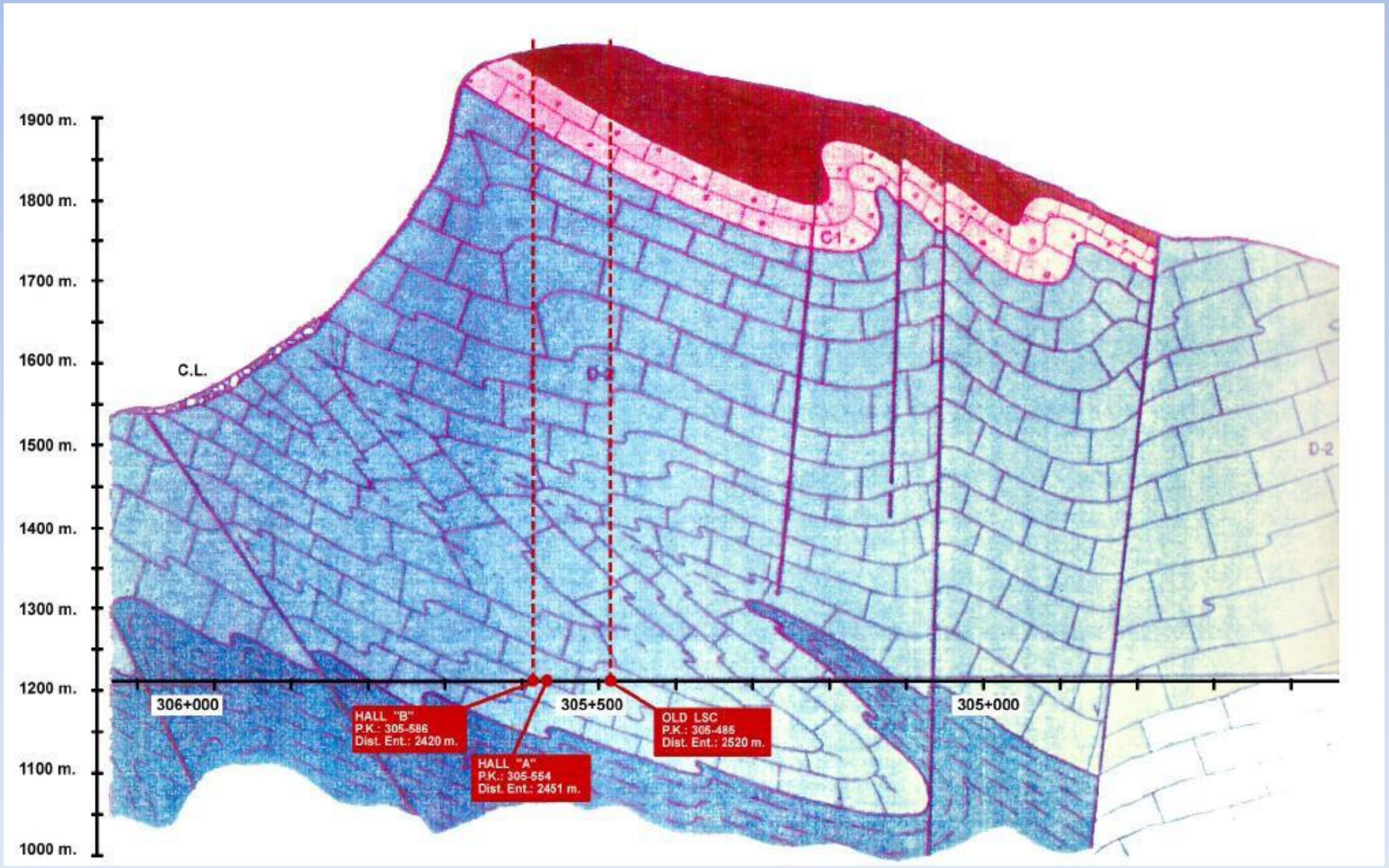
Status of the muon measurement in LSC

A. Bayo

Laboratorio Subterráneo de Canfranc (LSC)

MUON MONITOR WORKSHOP

Introduction



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Introduction

Depth (max.): ~ 2450 meters of water equivalent (m.w.e.)

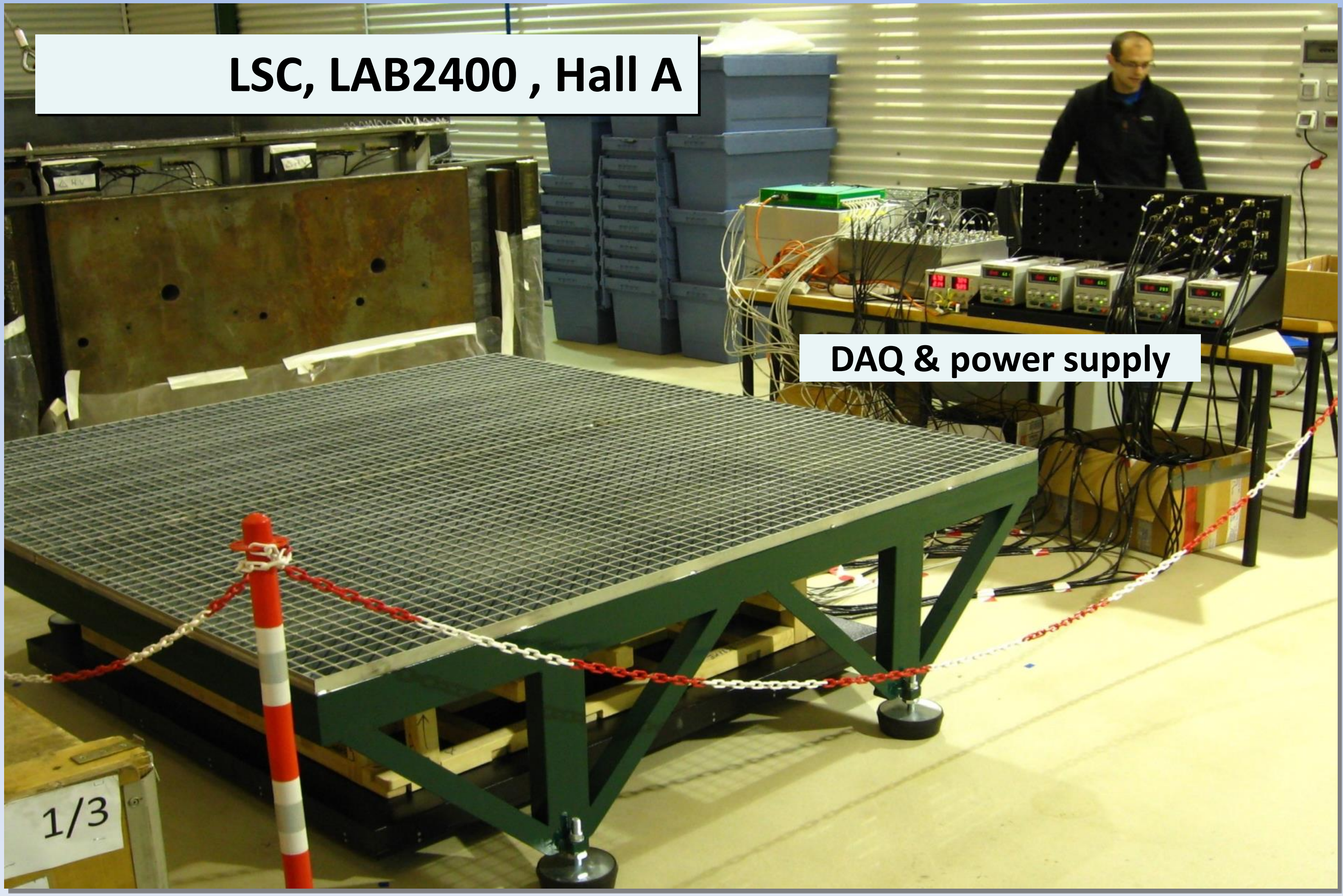
Composition of the rock and average density: limestone, mainly calcium carbonate, $\rho \sim 2.7\ g/cm^3$ plus traces of quartz, $\rho \sim 2.6\ g/cm^3$)

Expected Muon flux: $\phi_\mu = 2.5 \times 10^{-3}\ \mu/m^2s$

Hall B	$5.04 \pm 0.06(stat) \pm 0.5(sys)\ 10^{-3}\ \mu m^{-1}s^{-1}$	+28%
Hall A	$3.94 \pm 0.02(stat) \pm 0.4(sys)\ 10^{-3}\ \mu m^{-1}s^{-1}$	
Old Lab	$3.59 \pm 0.04(stat) \pm 0.4(sys)\ 10^{-3}\ \mu m^{-1}s^{-1}$	-9%

PRELIMINARY

Introduction



LSC
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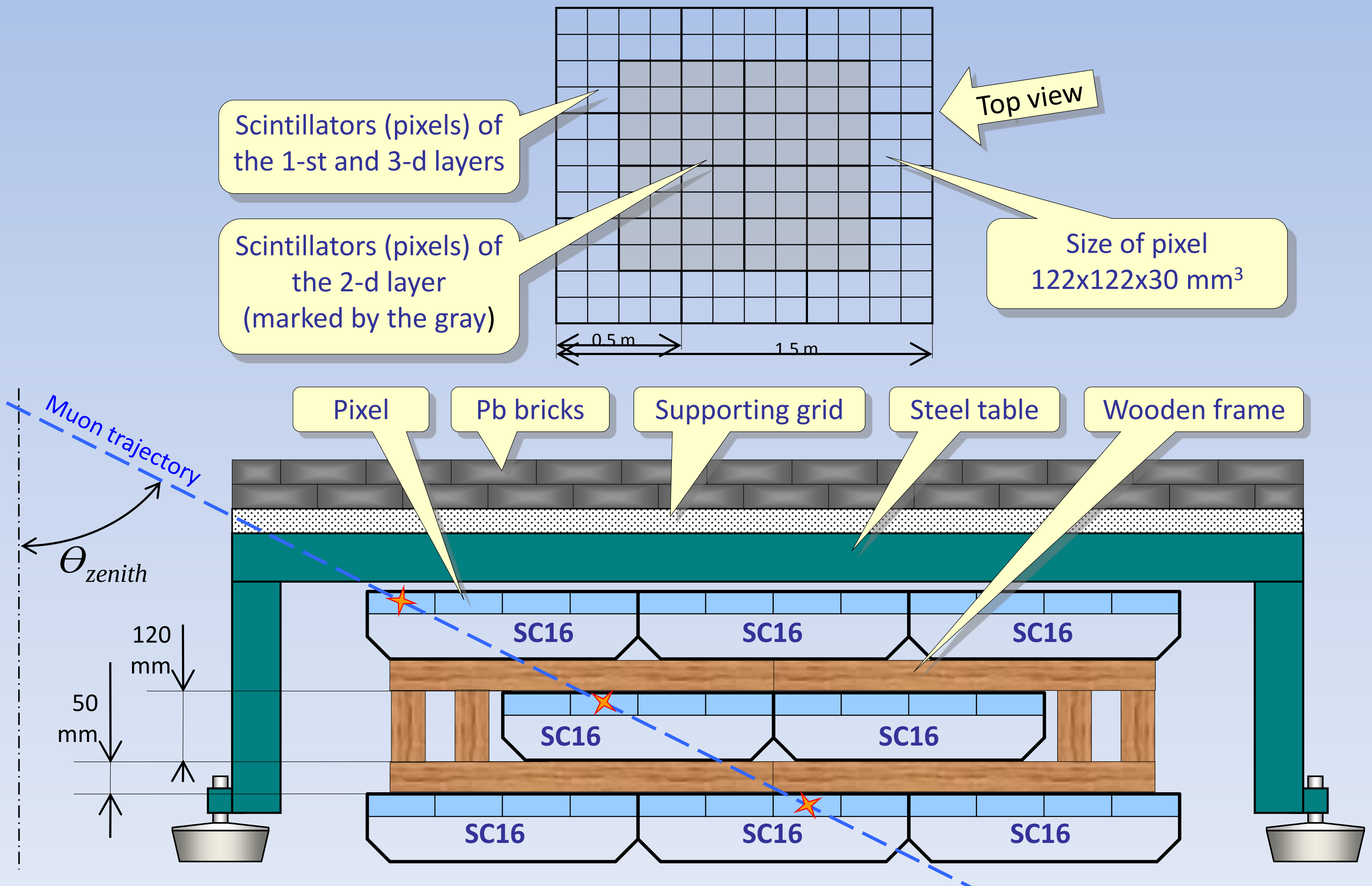
Introduction

Introduction



Raw data

0 -> trigger
1 -> module hit

Number of detector

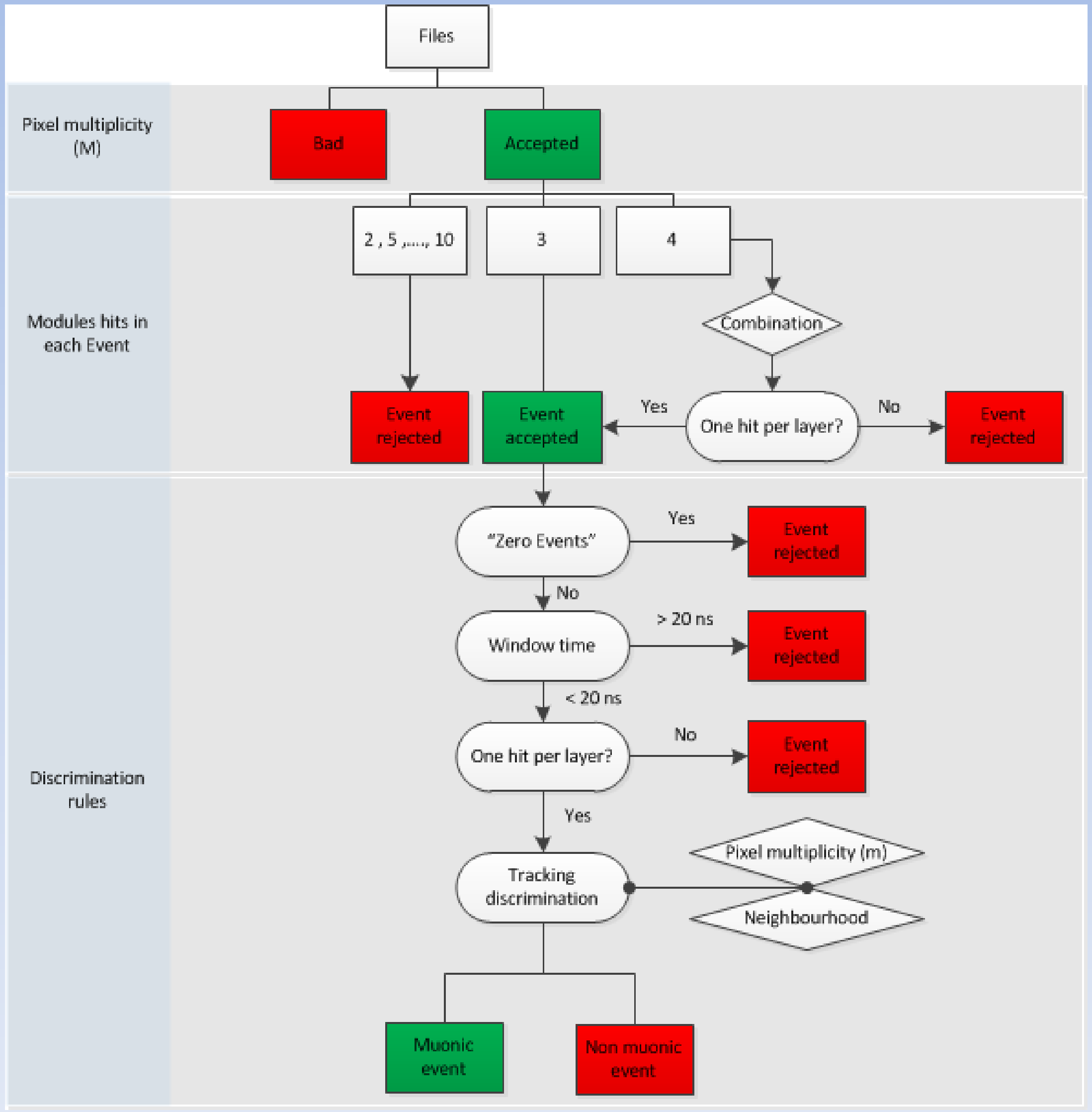
Hit time (10 ns units)

Pixel hit map information
px. 0 px.1 ....px15

```
0 0 297328 -1 -1 xxxxxxxxxxxxxxxx
1 76 37446 -1 -1 0100000000000000
1 92 37678 -1 -1 0111100000000010
1 81 37569 -1 -1 0000000000000001
1 72 37678 -1 -1 0111111000000100
0 1 649252 -1 -1 xxxxxxxxxxxxxxxx
1 76 37446 -1 -1 0110000000000000
1 92 37678 -1 -1 0000100000000010
0 2 750763 -1 -1 xxxxxxxxxxxxxxxx
1 93 37569 -1 -1 0000000000000001
1 81 37678 -1 -1 0000000000011100
1 72 37678 -1 -1 0110011000000100
0 3 1044791 -1 -1 xxxxxxxxxxxxxxxx
1 76 37446 -1 -1 0100000000000000
1 93 37678 -1 -1 0000000000000010
1 92 37678 -1 -1 0000000000000010
```

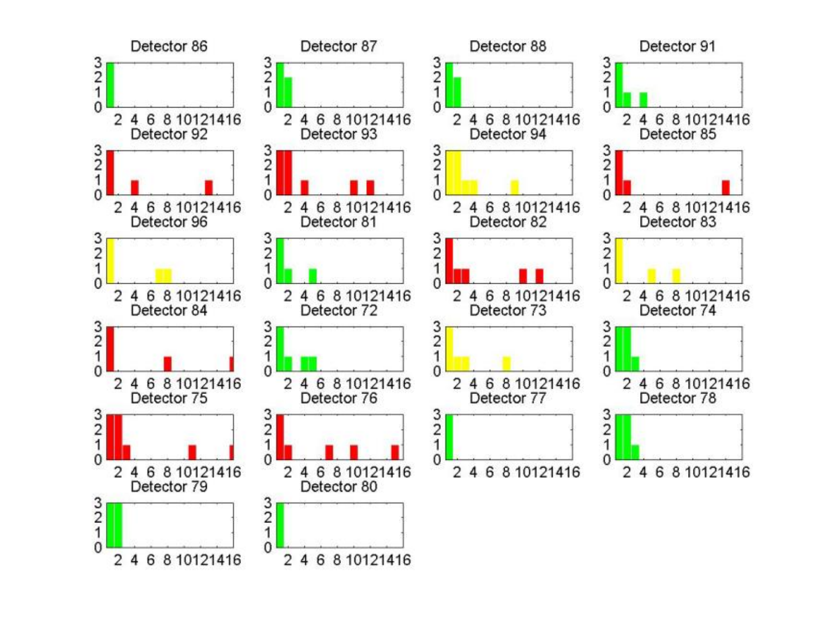
EVENT

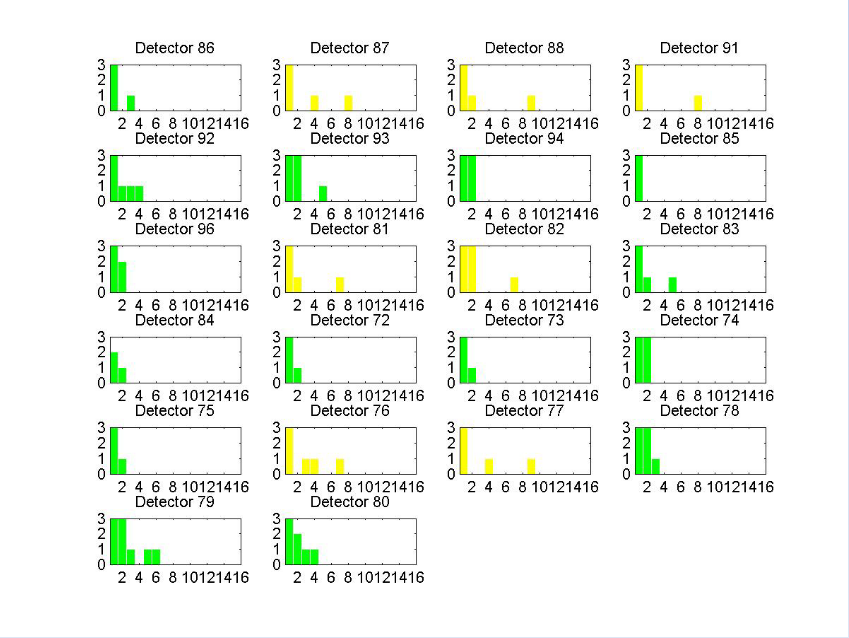
Discrimination rules



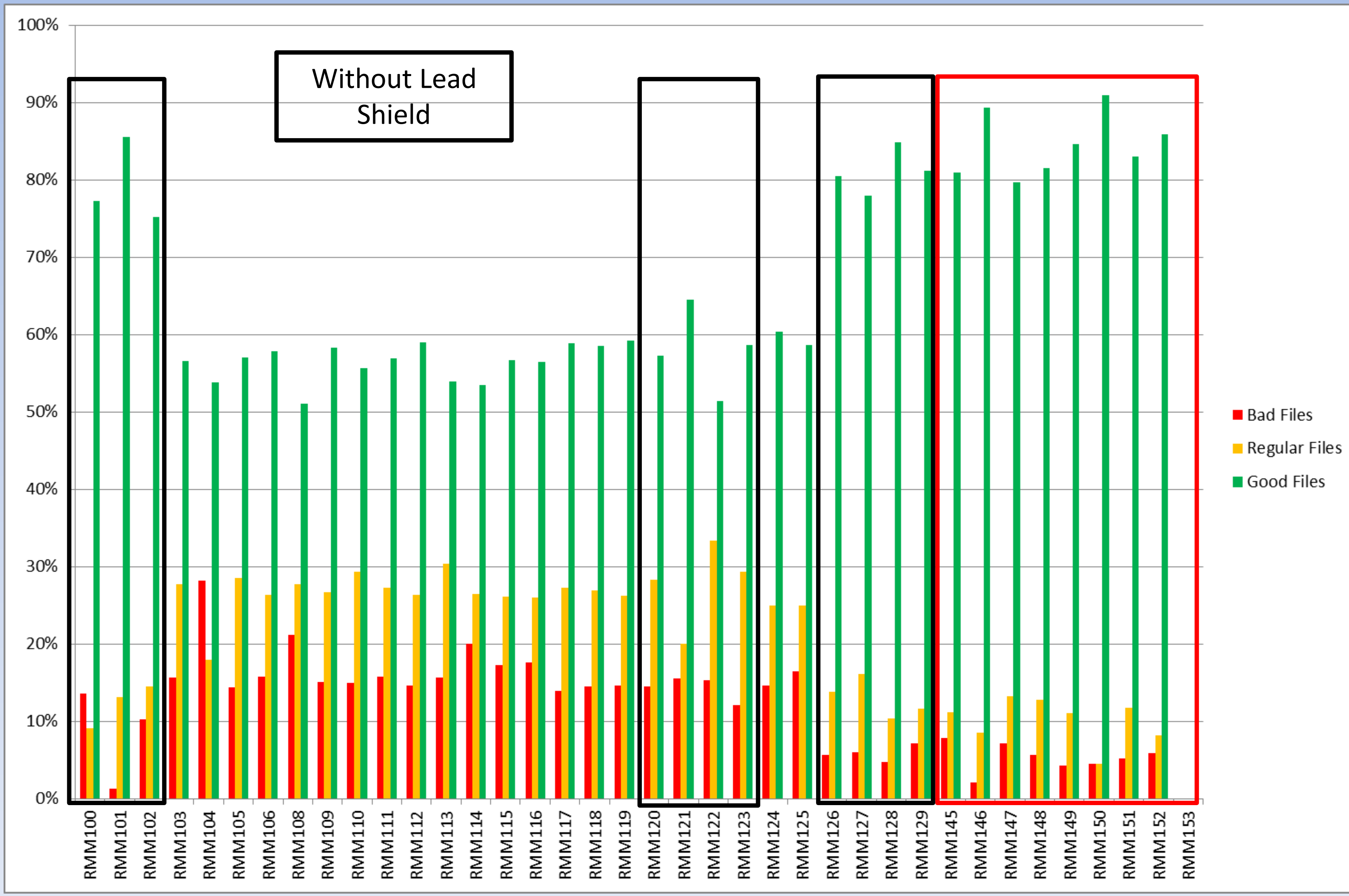
Multiplicity (M)

- Pixels multiplicity of one detector(M)
  - **M < 6** - accepted
  - **6 < M < 10**
    - less than 5 detectors - accepted (regular files)
    - more than 5 detectors - rejected
  - **M > 10** - rejected

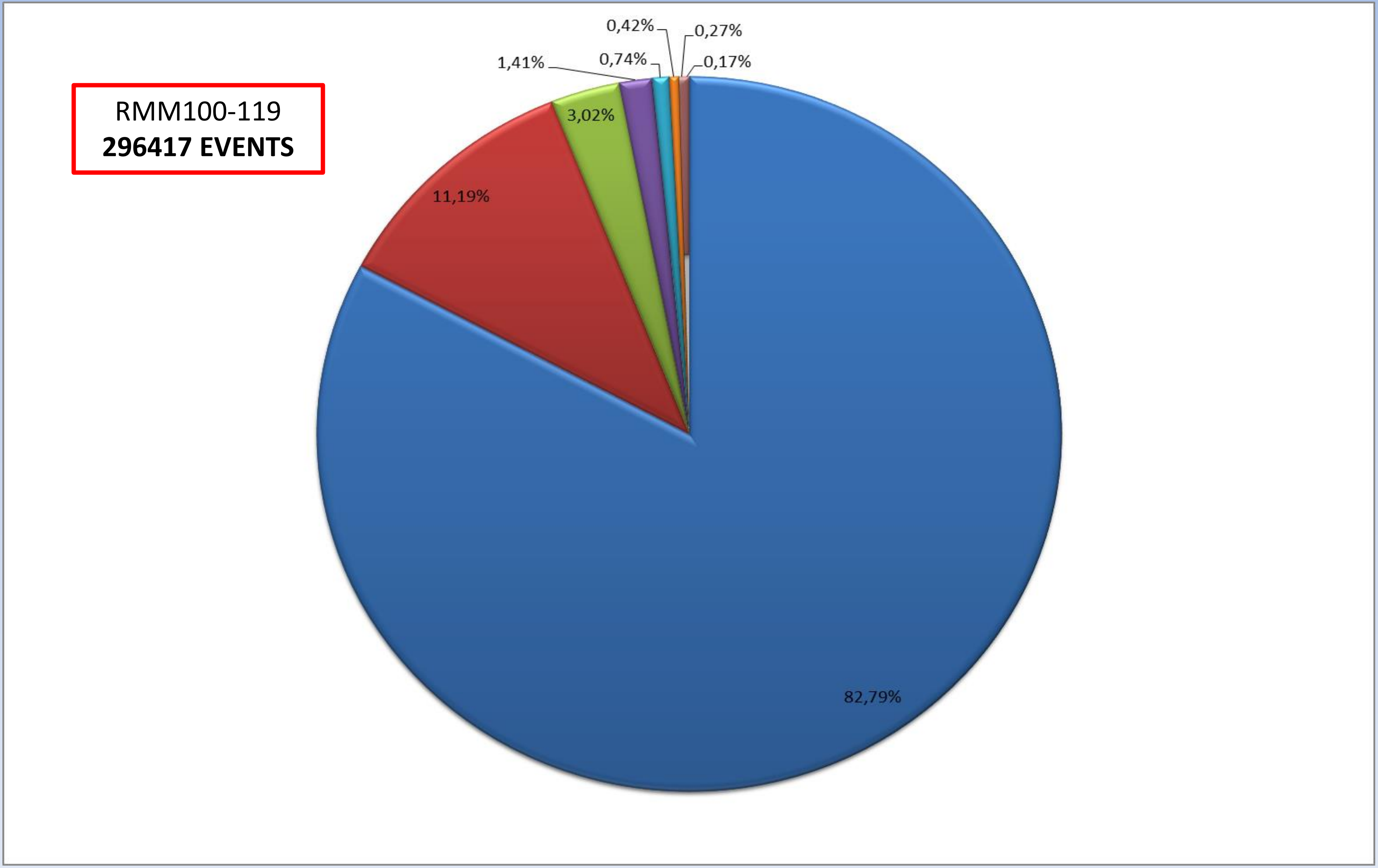




Multiplicity



Events groups



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Discrimination rules

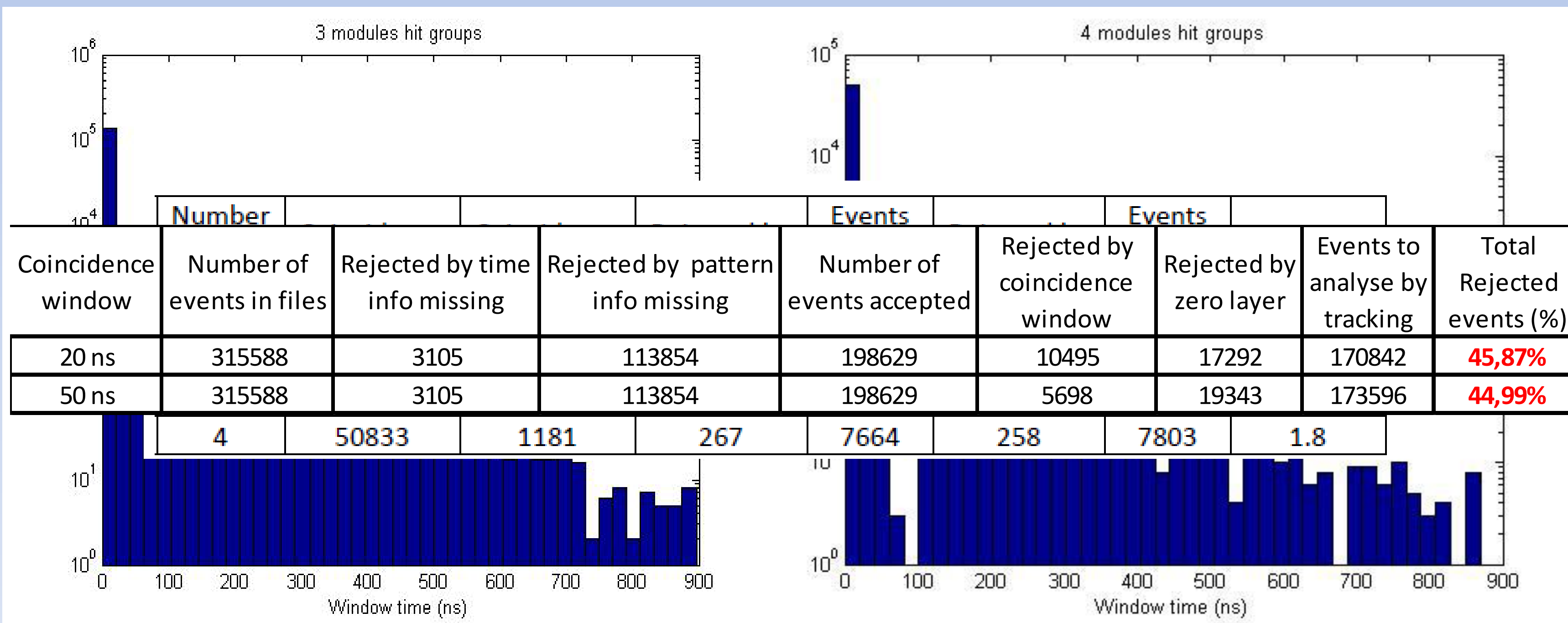
- “Zero events”
  - Pattern info missing
  - Time info missing

```
0 0 297328 -1 -1 xxxxxxxxxxxxxxxx
1 76 37446 -1 -1 0100000000000000
1 92 37678 -1 -1 0111100000000010
1 81 37569 -1 -1 0000000000000001
1 72 37678 -1 -1 0111111000000100
0 1 649252 -1 -1 xxxxxxxxxxxxxxxx
1 76 37446 -1 -1 0110000000000000
1 92 37678 -1 -1 0000100000000010
0 2 750763 -1 -1 xxxxxxxxxxxxxxxx
1 93 37569 -1 -1 0000000000000001
1 81 37678 -1 -1 0000000000011100
1 72 37678 -1 -1 0110011000000100
0 3 1044791 -1 -1 xxxxxxxxxxxxxxxx
1 76 37446 -1 -1 0100000000000000
1 93 37678 -1 -1 0000000000000000
1 92 37678 -1 -1 0000000000000010
0 4 1149151 -1 -1 xxxxxxxxxxxxxxxx
1 91 37569 -1 -1 0000000000000001
1 82 42053 -1 -1 0000000000000000
1 74 37678 -1 -1 0000000000000100
0 4 1349151 -1 -1 xxxxxxxxxxxxxxxx
1 87 37569 -1 -1 0000000000000001
1 83 0 -1 -1 0000000000001000
1 79 37678 -1 -1 0000000000000100
0 4 1449151 -1 -1 xxxxxxxxxxxxxxxx
1 85 37569 -1 -1 0000000000000001
1 83 37553 -1 -1 0000000000001000
1 77 37678 -1 -1 0000000000000100
```

Discrimination rules

- Window Time (RMM100-RMM110)

$t_2 - t_1$ $t_3 - t_2$ $t_3 - t_1$



Coincidence window	Number of events in files	Rejected by time info missing	Rejected by pattern info missing	Number of events accepted	Rejected by coincidence window	Rejected by zero layer	Events to analyse by tracking	Total Rejected events (%)
20 ns	315588	3105	113854	198629	10495	17292	170842	**45,87%**
50 ns	315588	3105	113854	198629	5698	19343	173596	**44,99%**

Discrimination rules

- Tracking discrimination - neighbourhood

Neighbourhood (by shifts)

First neighbour	n=1
Second	$n=\sqrt{2}$
Third	n=2
Fourth	$n=\sqrt{5}$
Fifth	$n=\sqrt{8}$
Sixth	n=3
...	

$\sqrt{18}$	$\sqrt{13}$	$\sqrt{10}$	3	$\sqrt{10}$	$\sqrt{13}$	$\sqrt{18}$
$\sqrt{13}$	$\sqrt{8}$	$\sqrt{5}$	2	$\sqrt{5}$	$\sqrt{8}$	$\sqrt{13}$
$\sqrt{10}$	$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$	$\sqrt{10}$
3	2	1	Pixel Hit	1	2	3
$\sqrt{10}$	$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$	$\sqrt{10}$
$\sqrt{13}$	$\sqrt{8}$	$\sqrt{5}$	2	$\sqrt{5}$	$\sqrt{8}$	$\sqrt{13}$
$\sqrt{18}$	$\sqrt{13}$	$\sqrt{10}$	3	$\sqrt{10}$	$\sqrt{13}$	$\sqrt{18}$

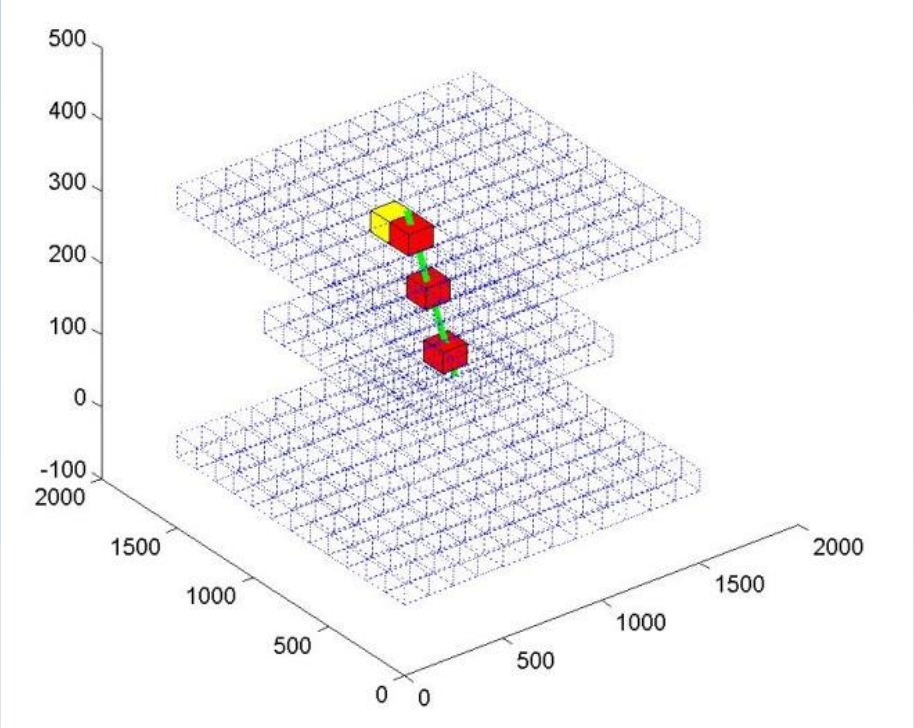
Neighbourhood (by Δx/Δy)

First neighbour	Δx and/or Δy =125.
Second neighbour	Δx and/or Δy =250.
Third neighbour	Δx and/or Δy =375.

375	375	375	375	375	375	375
375	250	250	250	250	250	375
375	250	125	125	125	250	375
375	250	125	Pixel Hit	125	250	375
375	250	125	125	125	250	375
375	250	250	250	250	250	375
375	375	375	375	375	375	375

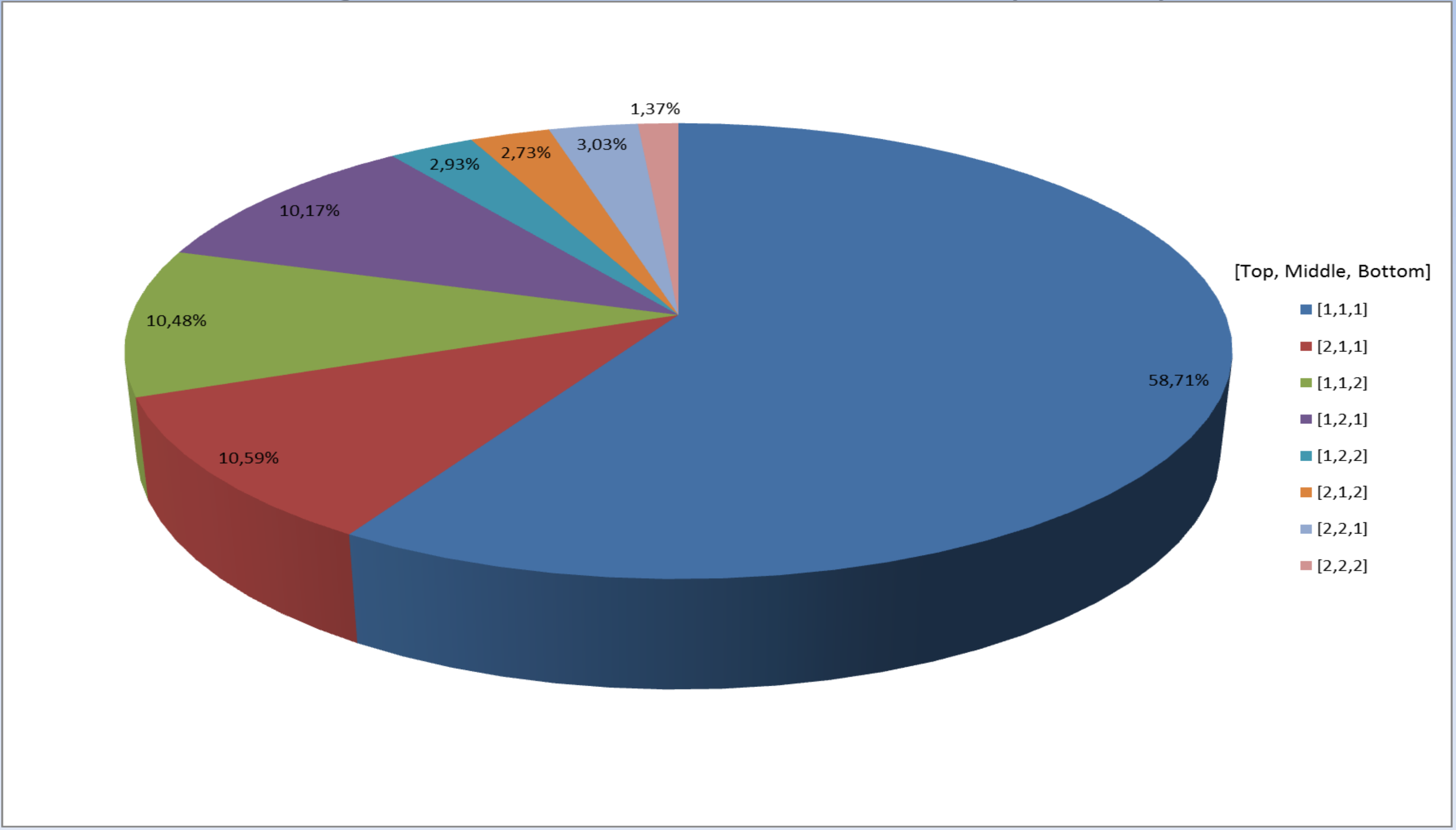
Discrimination rules

- Tracking discrimination
  - 8 straight lines (corner top – corner bottom)
  - 5 faces of middle layer pixel



Discrimination rules

- Tracking discrimination - multiplicity



Discrimination rules

Zenith angle

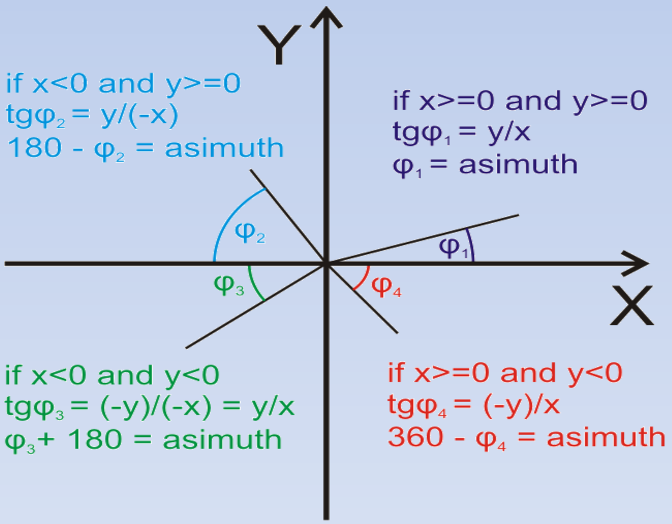
$$\theta = arctan\left(\frac{\sqrt{(x_{top} - x_{bottom})^2 + (y_{top} - y_{bottom})^2}}{z_{top} - z_{bottom}}\right)$$

We have fixed θ = 0 when:

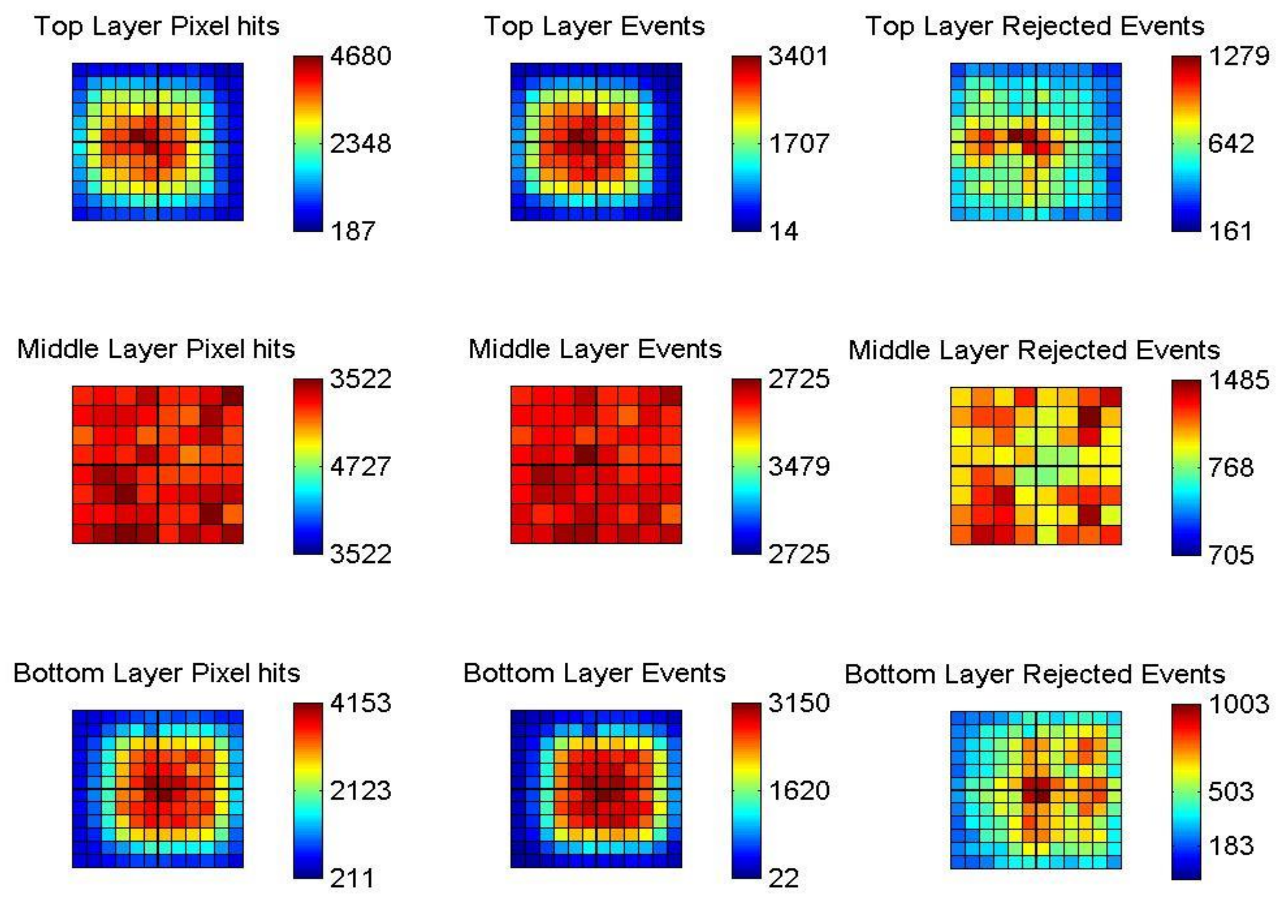
- x_{top} - x_{bottom} = 0
- x_{top} - x_{middle} = 0
- x_{middle} - x_{bottom} = 0

Azimuth angle

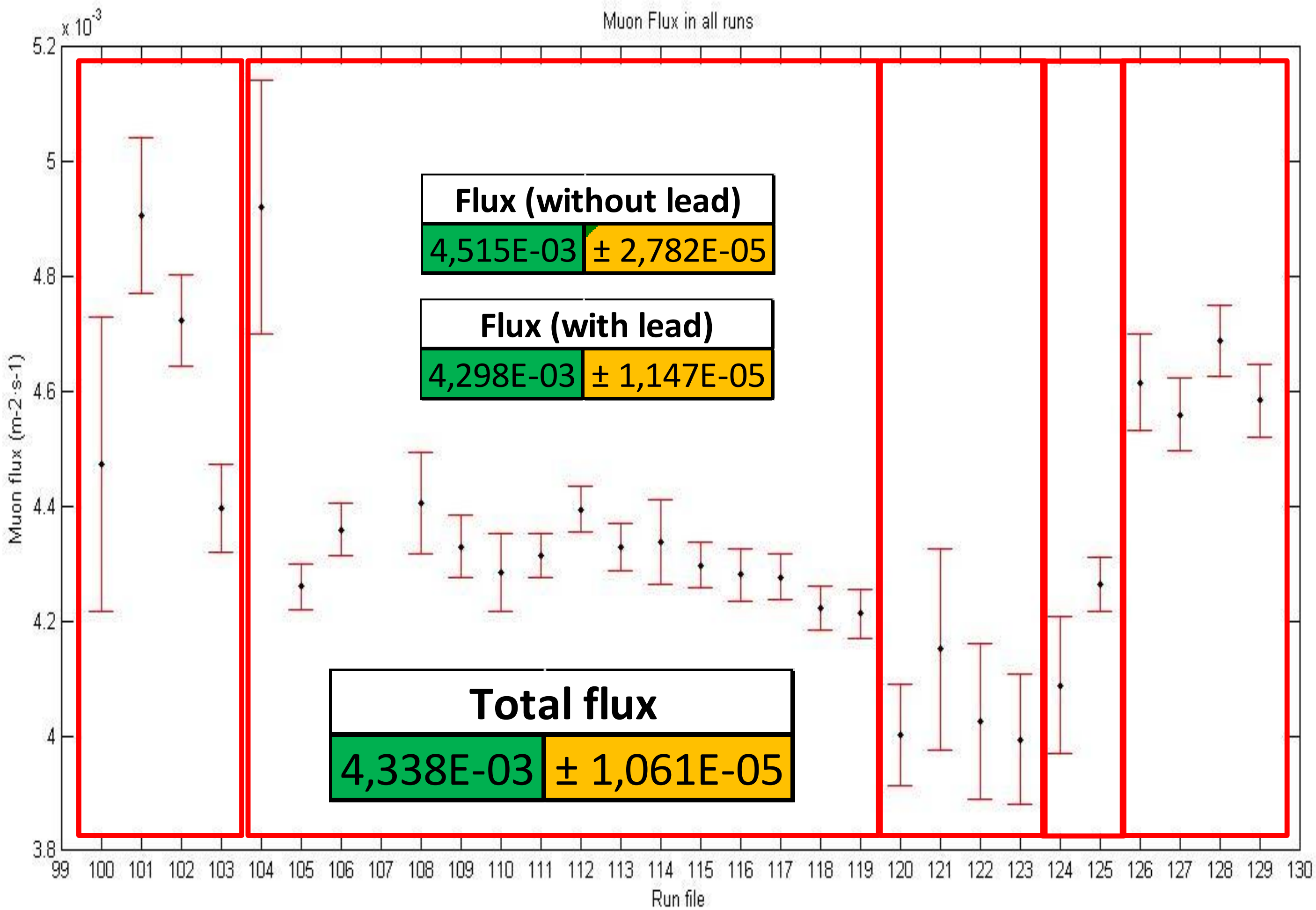
$$\varphi = \arctan\left(\frac{y_{top} - y_{bottom}}{x_{top} - x_{bottom}}\right)$$



Results – LAB2400

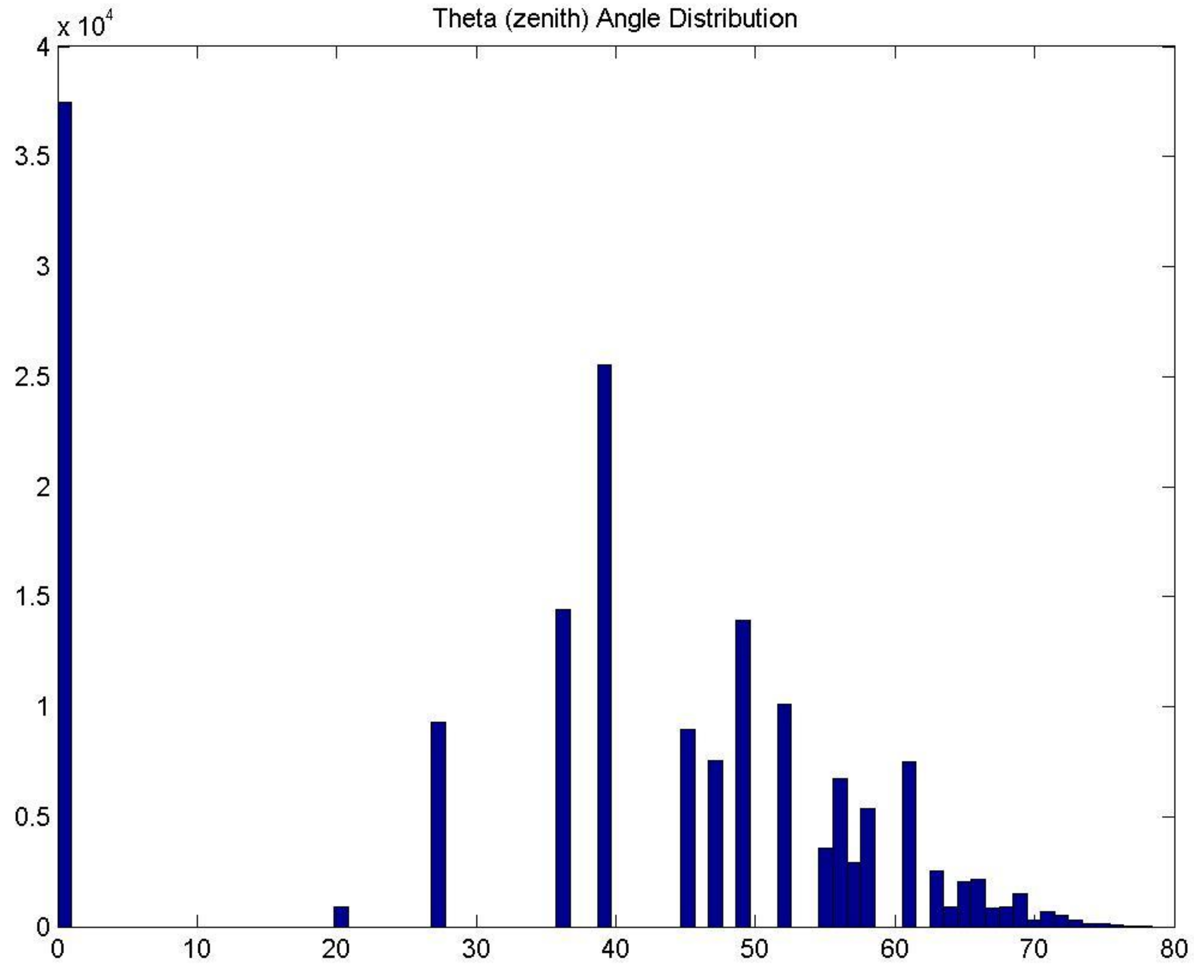


Results – LAB2400

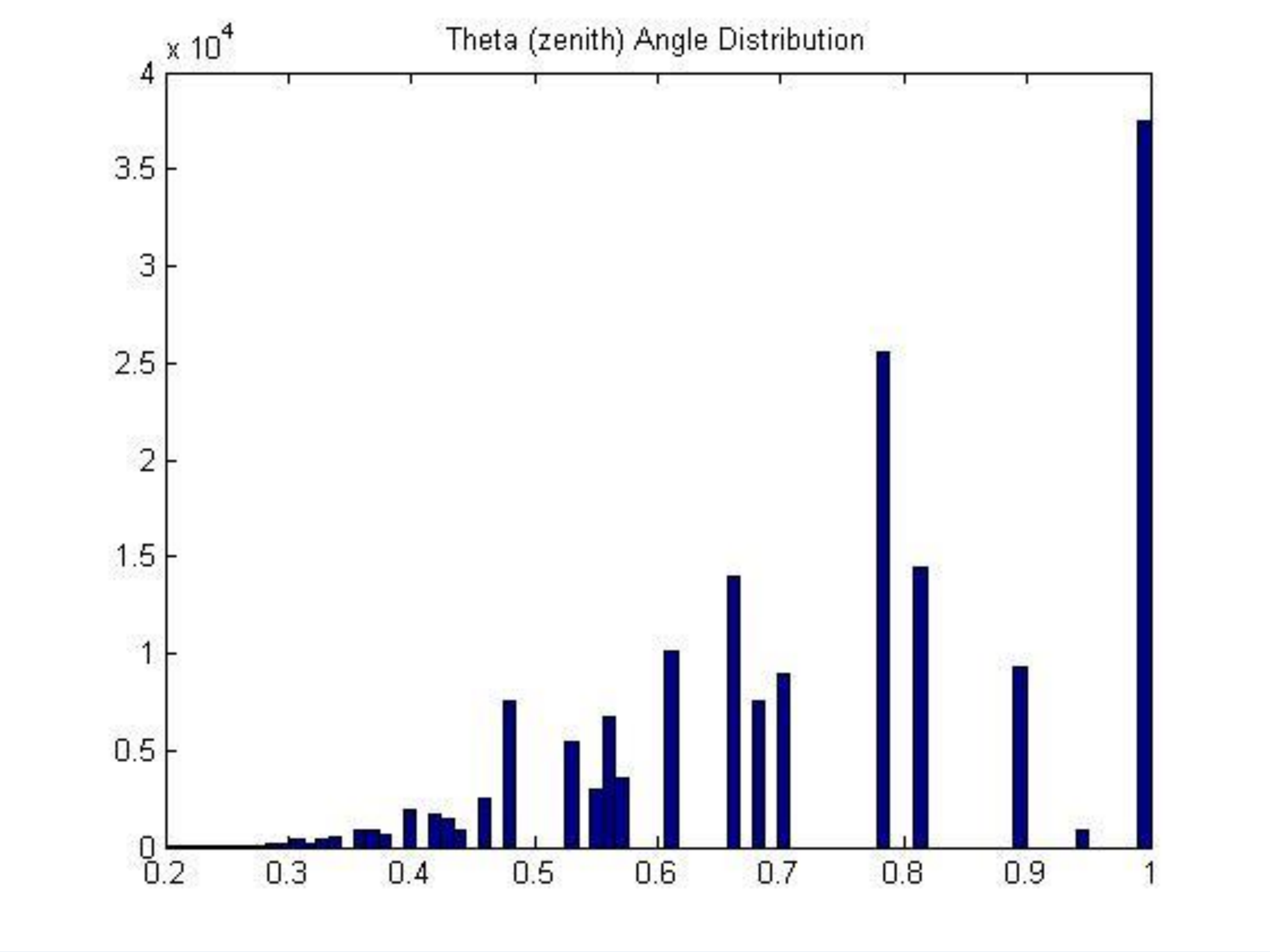


Around 446 days of "good" data

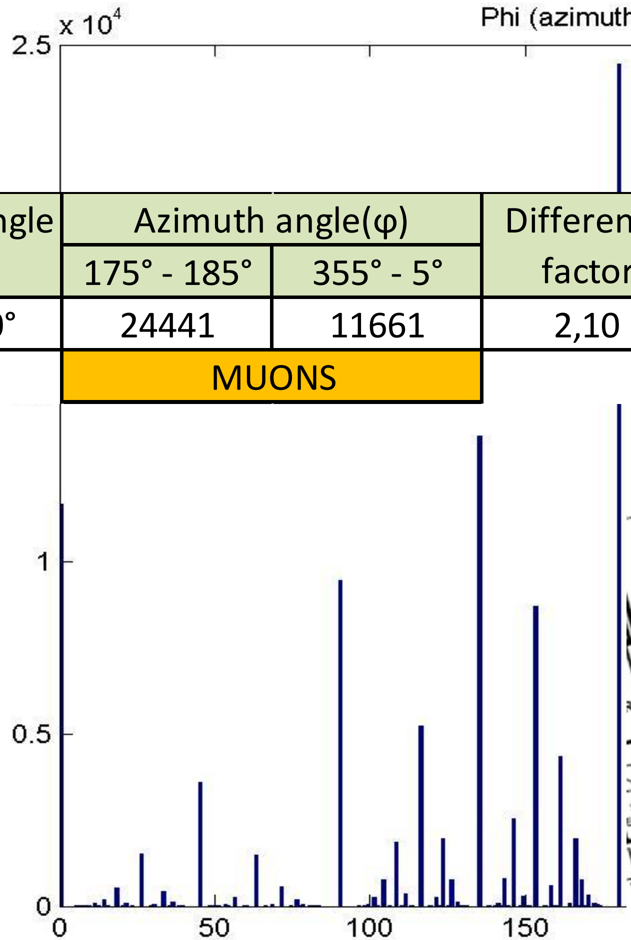
Results – LAB2400



Results – LAB2400

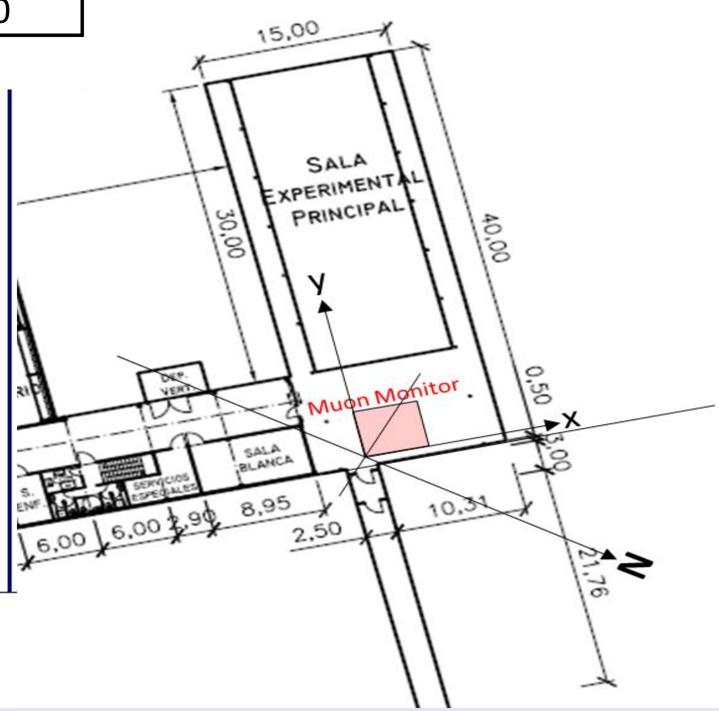


Results – LAB2400



Zenith angle (θ)	Azimuth angle(φ)		Difference factor
	175° - 185°	355° - 5°	
0° – 90°	24441	11661	2,10
	MUONS		

Rioseta Valley
(minimun rock thickness)
φ ≈ 180 º



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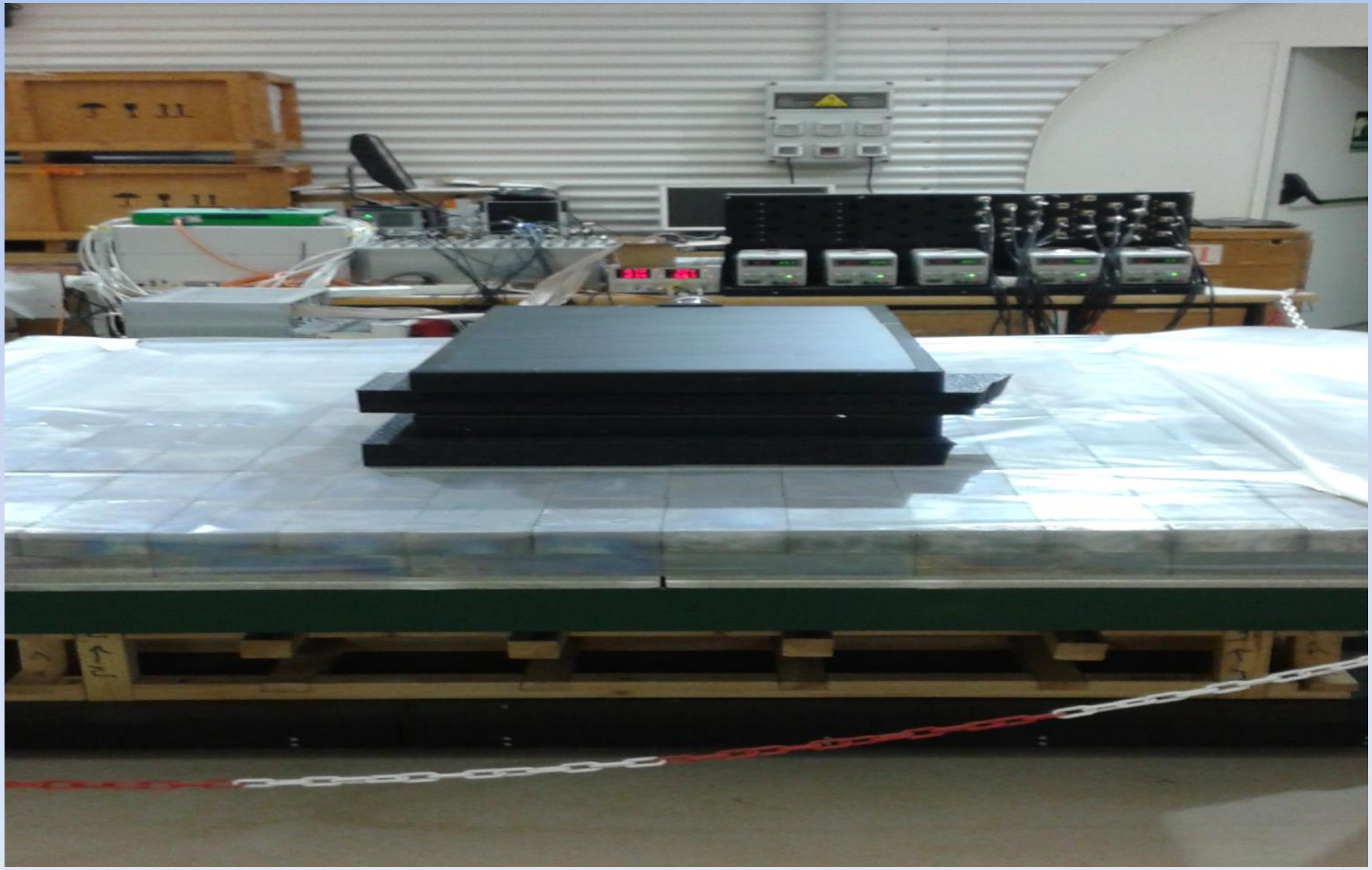
Results – LAB2400

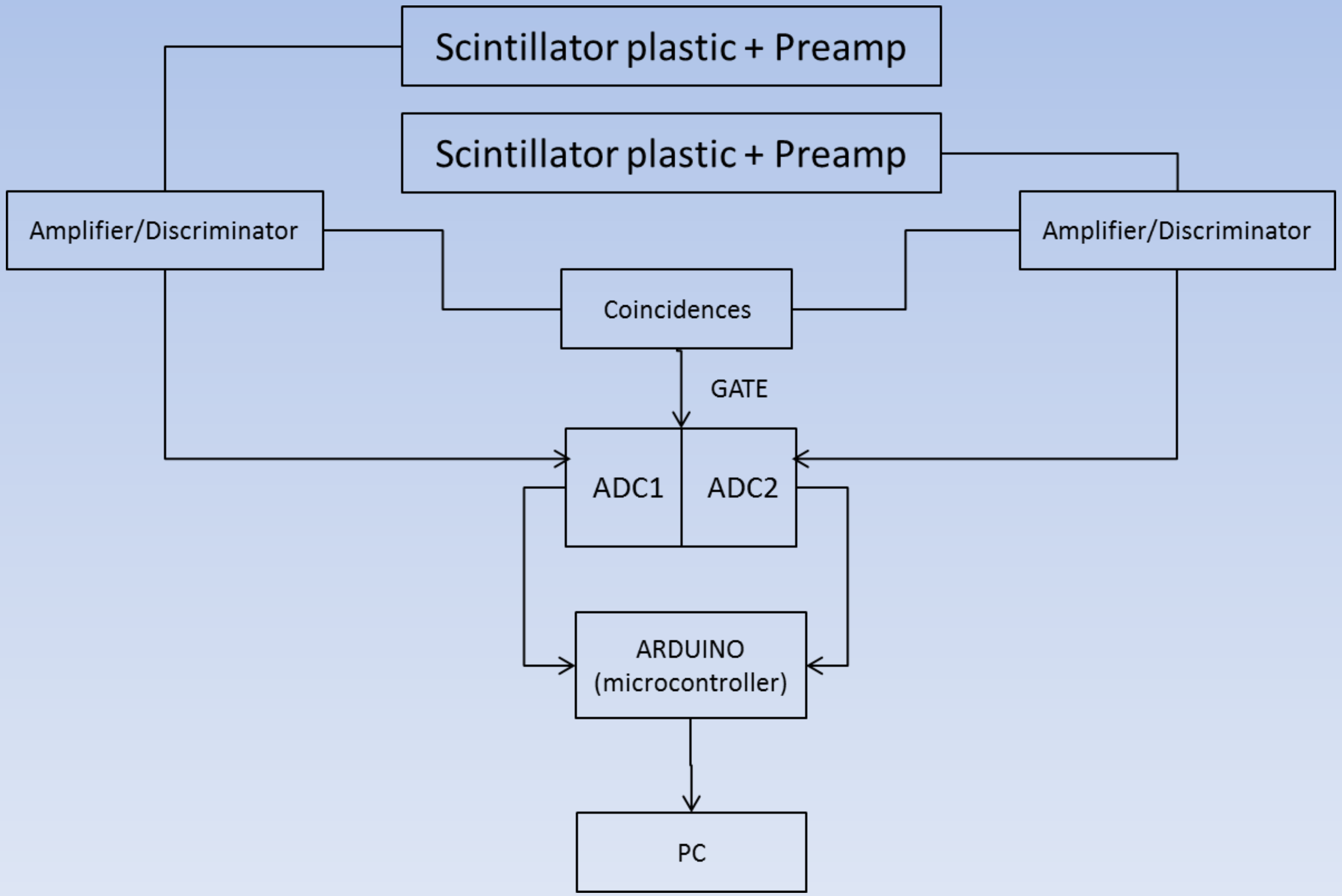
Detector	px 0	px 1	px 2	px 3	px 4	px 5	px 6	px 7	px 8	px 9	px 10	px 11	px 12	px 13	px 14	px 15
86	135.063	136.972	171.695	189.562	128.402	176.392	92.671	138.188	137.170	121.652	165.393	105.769	187.916	201.959	97.851	165.181
87	233.227	295.333	247.141	132.674	138.850	241.494	182.442	69.671	148.348	153.925	161.227	275.981	280.981	134.324	124.048	267.683
88	135.798	164.872	102.436	113.747	99.190	38.801	215.654	99.402	95.837	181.956	136.789	184.981	199.302	146.591	122.804	123.596
91	224.333	203.558	217.445	133.037	190.574	75.985	171.354	161.821	179.163	134.966	157.990	117.990	223.906	121.086	126.776	127.922
92	53.140	303.832	263.687	191.586	284.722	310.748	168.026	210.414	184.898	375.892	118.483	292.978	299.701	233.767	160.594	169.616
93	240.142	294.177	224.566	207.814	244.012	231.741	334.692	285.082	256.809	278.888	251.006	251.918	311.930	272.041	286.462	317.405
94	207.833	269.380	275.388	229.468	225.360	219.631	142.851	198.271	175.703	238.997	295.533	187.485	187.438	186.743	175.700	149.719
85	190.932	89.459	304.206	161.717	113.020	178.566	142.011	13.964	187.369	221.149	323.115	253.395	268.746	269.407	152.271	116.595
96	298.964	294.175	224.926	217.250	291.422	248.653	263.933	272.466	233.203	284.796	237.724	195.862	25.132	318.269	232.500	181.766
81	4.844	4.976	5.432	5.085	5.128	5.192	5.136	4.482	4.842	5.238	5.257	6.424	5.455	5.323	5.194	6.068
82	5.160	5.256	6.024	5.204	4.903	5.618	5.957	5.271	5.383	5.439	6.007	5.952	5.323	6.019	5.839	5.166
83	4.796	5.047	4.352	5.054	4.934	4.521	4.740	4.823	4.392	5.564	5.082	5.377	4.404	6.411	5.186	5.808
84	5.362	4.642	5.356	5.065	5.587	5.499	5.098	5.211	5.276	5.905	5.427	5.478	5.536	5.481	4.822	4.848
80	148.362	92.546	249.621	144.266	177.408	345.637	142.828	68.695	166.011	227.066	88.753	87.255	130.674	183.737	70.815	145.353
79	347.622	183.412	292.859	224.805	294.102	237.604	267.179	320.333	261.106	243.696	251.824	135.909	248.321	300.449	95.616	227.128
78	111.289	166.887	99.927	100.876	64.217	71.175	40.353	49.494	113.315	34.516	134.600	123.738	92.914	93.543	20.041	84.450
77	47.747	40.980	46.503	74.460	148.706	54.631	145.043	86.225	71.928	175.305	38.631	139.467	35.359	49.395	62.359	192.989
76	276.652	457.582	155.598	139.492	607.559	378.426	309.839	250.265	424.924	266.020	406.184	288.761	255.851	163.121	152.401	232.012
75	286.828	390.862	276.840	105.510	170.163	173.632	274.388	138.569	356.420	275.394	194.464	250.556	254.833	159.020	199.375	180.903
74	332.227	144.247	211.039	169.129	159.484	137.711	142.060	302.676	184.948	183.658	138.313	89.931	257.143	114.821	113.275	180.087
73	282.875	138.178	315.026	296.020	330.016	252.619	272.487	155.617	321.051	171.072	156.926	194.811	396.675	74.466	166.205	382.304
72	333.197	295.304	298.835	74.719	143.901	387.337	354.111	82.600	289.714	244.487	207.099	245.204	125.942	322.931	237.849	60.180

Scintillator plastics

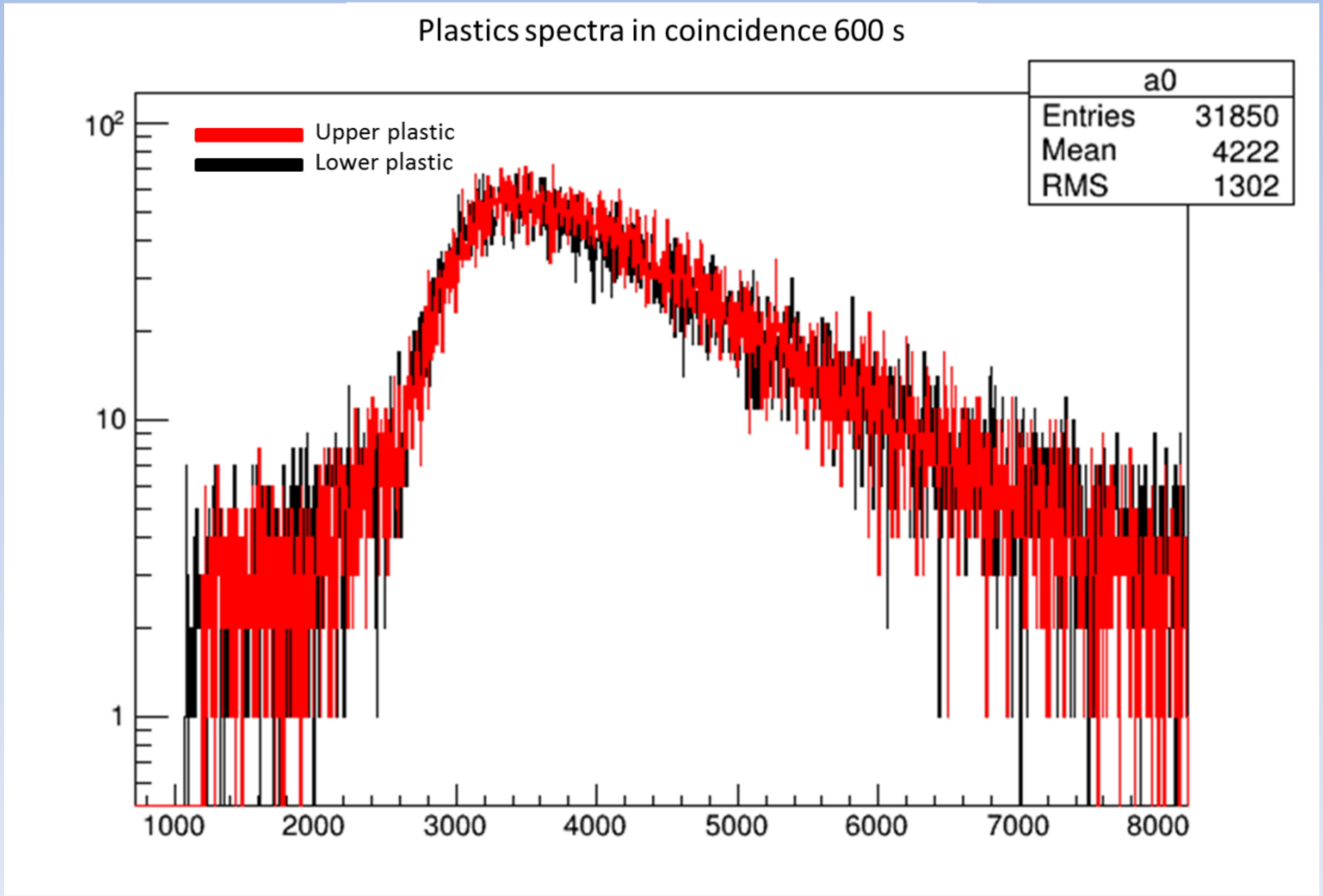
2 SCIONIX detectors (1000 x 500 x 50 mm^3)



Scintillator plastics



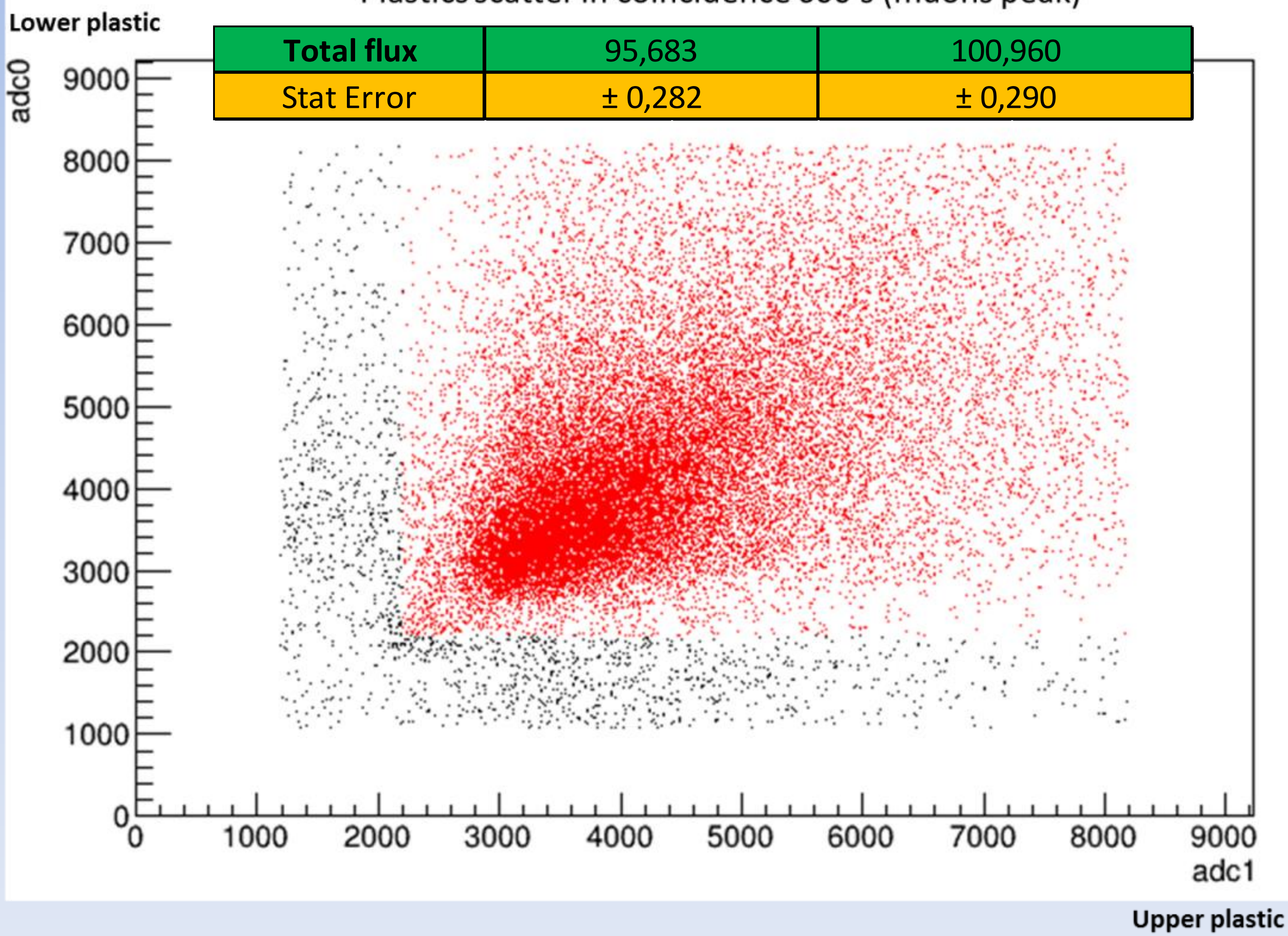
Scintillator plastics



Scintillator plastics

Plastics scatter in coincidence 600 s (muons peak)

Total flux	95,683	100,960
Stat Error	± 0,282	± 0,290



Scintillator plastics

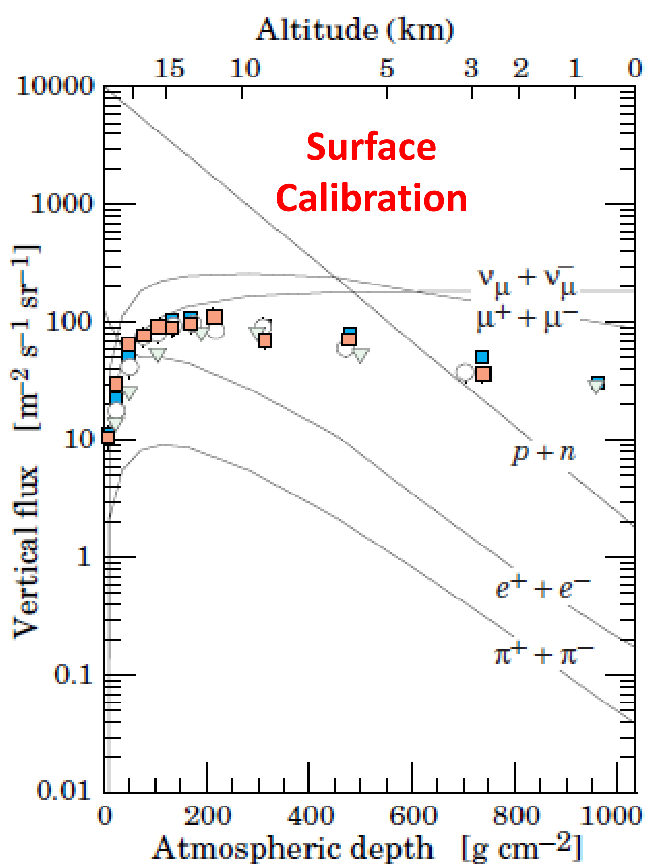


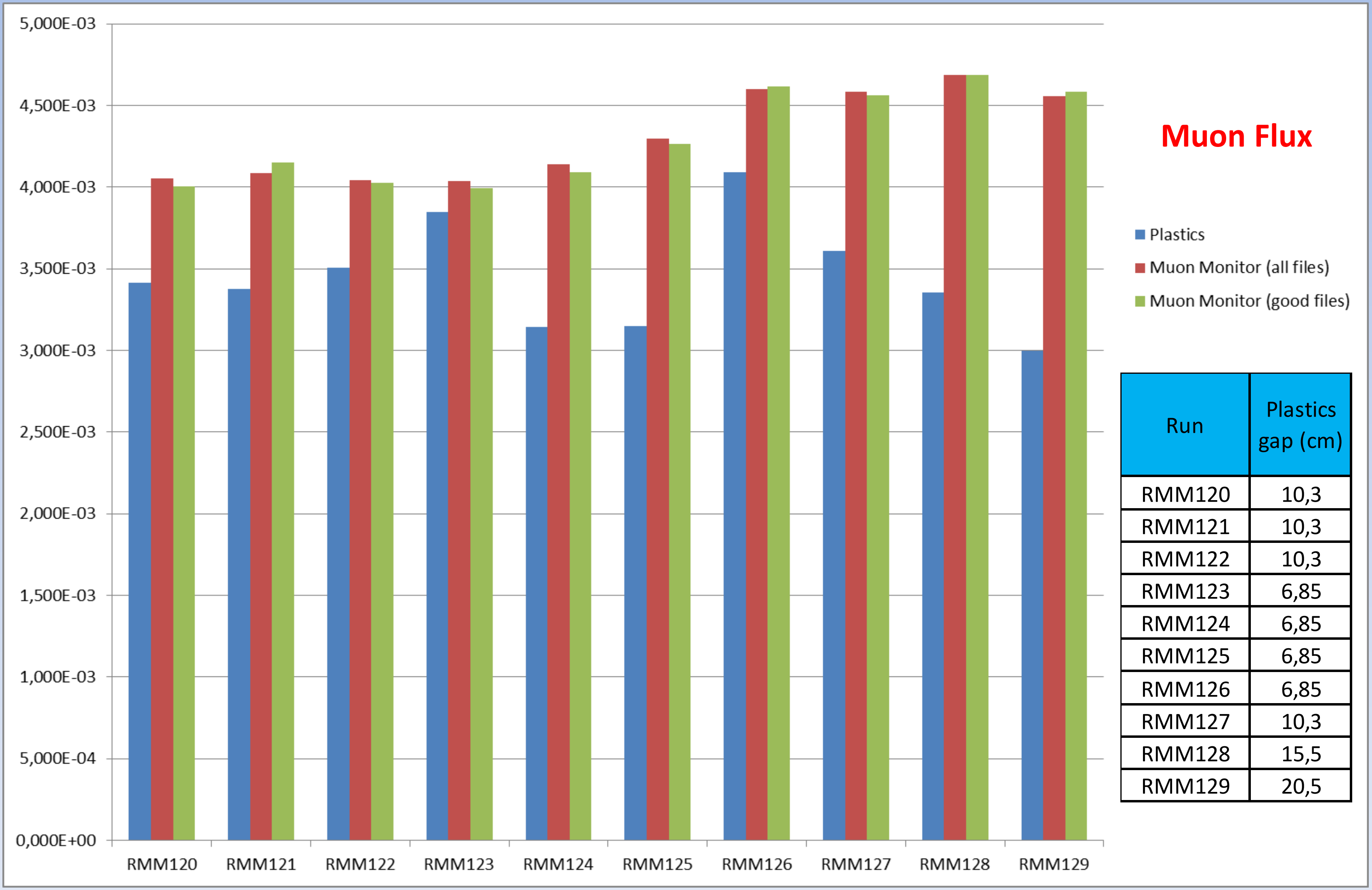
Figure 28.4: Vertical fluxes of cosmic rays in the atmosphere with $E > 1$ GeV estimated from the nucleon flux of Eq. (28.2). The points show measurements of negative muons with $E_\mu > 1$ GeV [39–43].

Particle Data Group, Review of Partyicle Physics, Chinese Physics C Vol. 38, No. 9 (2014) 090001

Material Attenuation ????

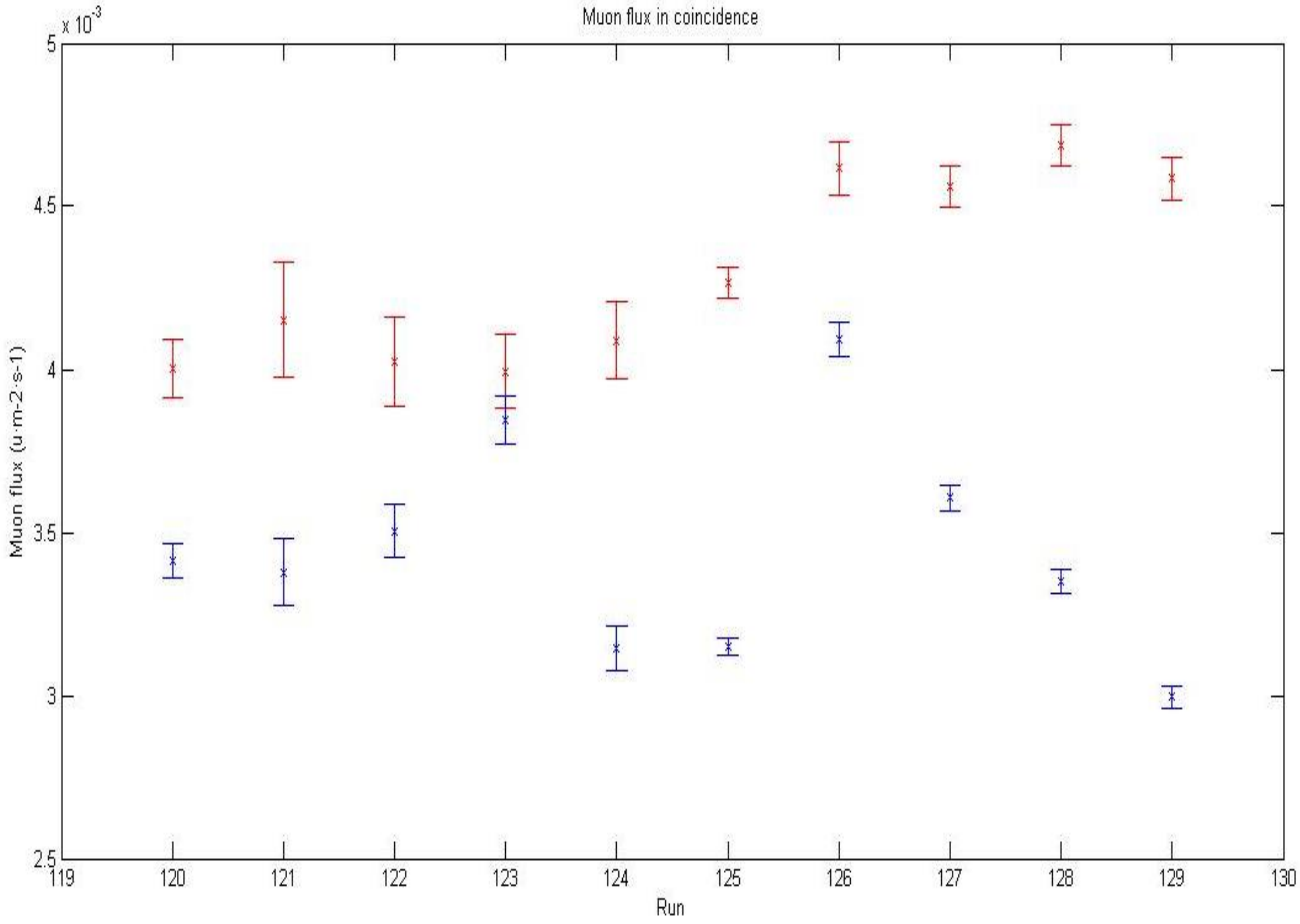
- 600 mm concrete
- 200 mm light concrete
- 100 mm extruded polystyrene
- …….

Scintillator plastics



Run	Plastics gap (cm)
RMM120	10,3
RMM121	10,3
RMM122	10,3
RMM123	6,85
RMM124	6,85
RMM125	6,85
RMM126	6,85
RMM127	10,3
RMM128	15,5
RMM129	20,5

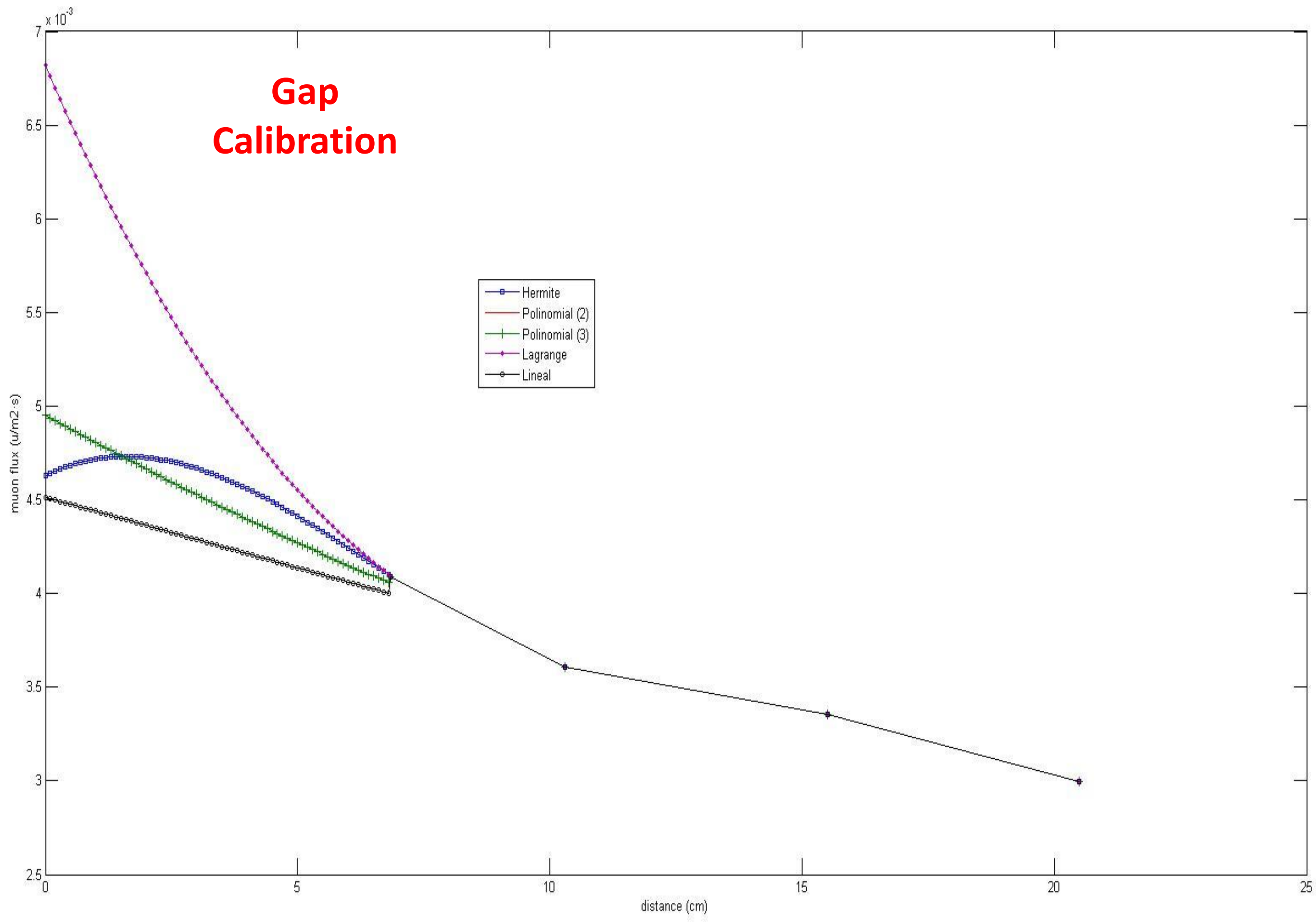
Scintillator plastics



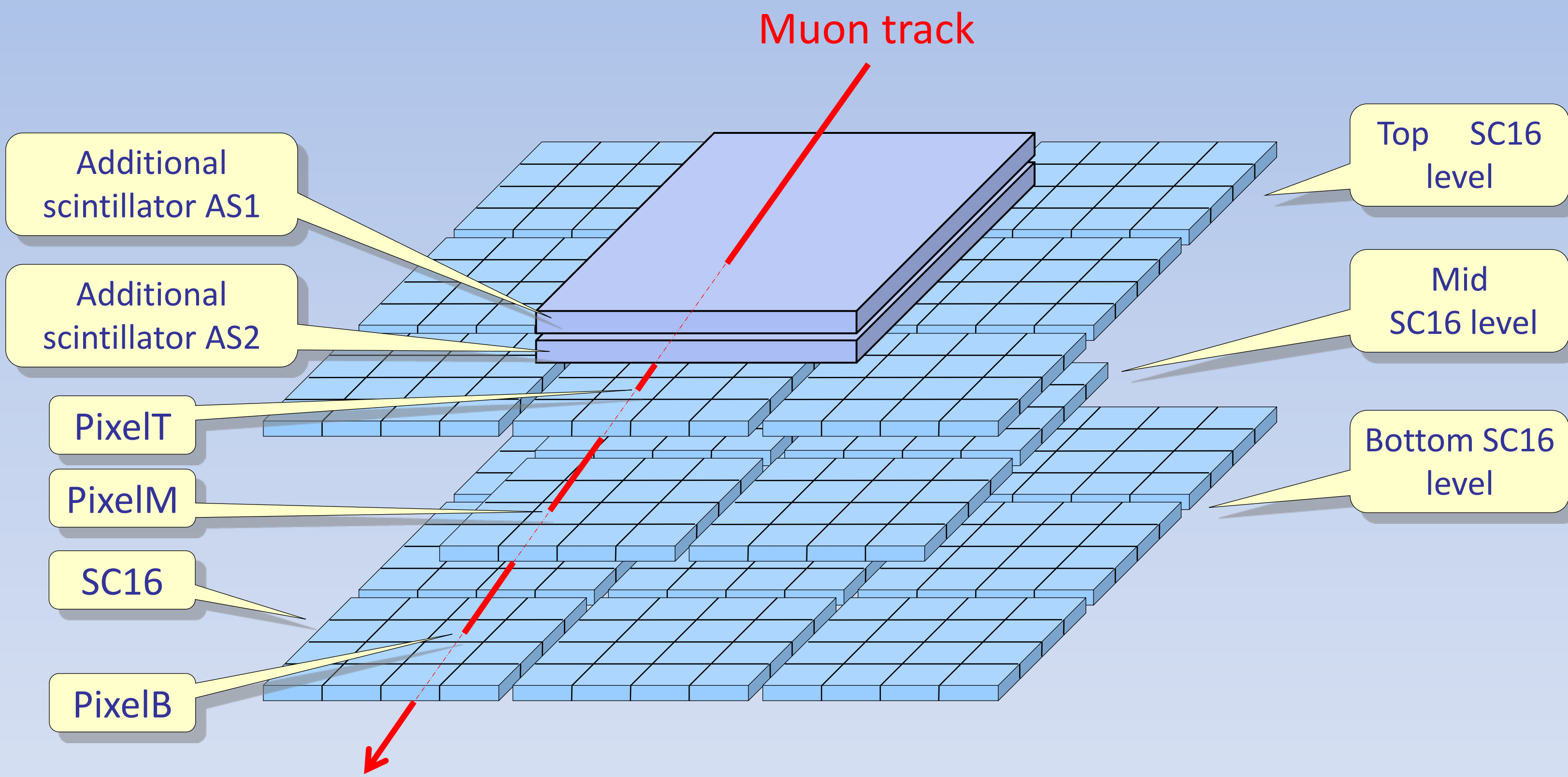
- **Plastics**
- **Muon monitor**

Run	Plastics gap (cm)
RMM120	10,3
RMM121	10,3
RMM122	10,3
RMM123	6,85
RMM124	6,85
RMM125	6,85
RMM126	6,85
RMM127	10,3
RMM128	15,5
RMM129	20,5

Scintillator plastics

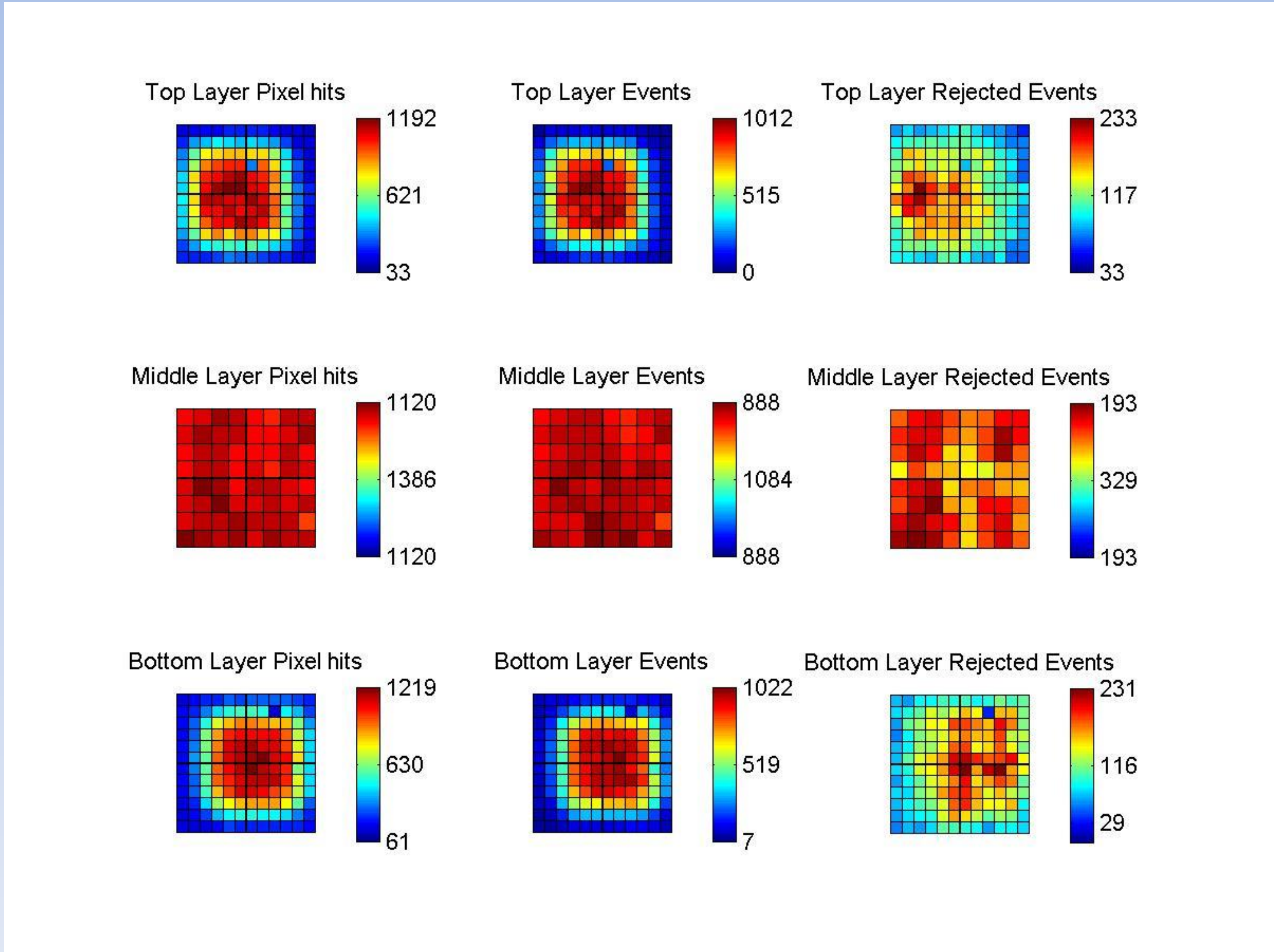


Scintillator plastics

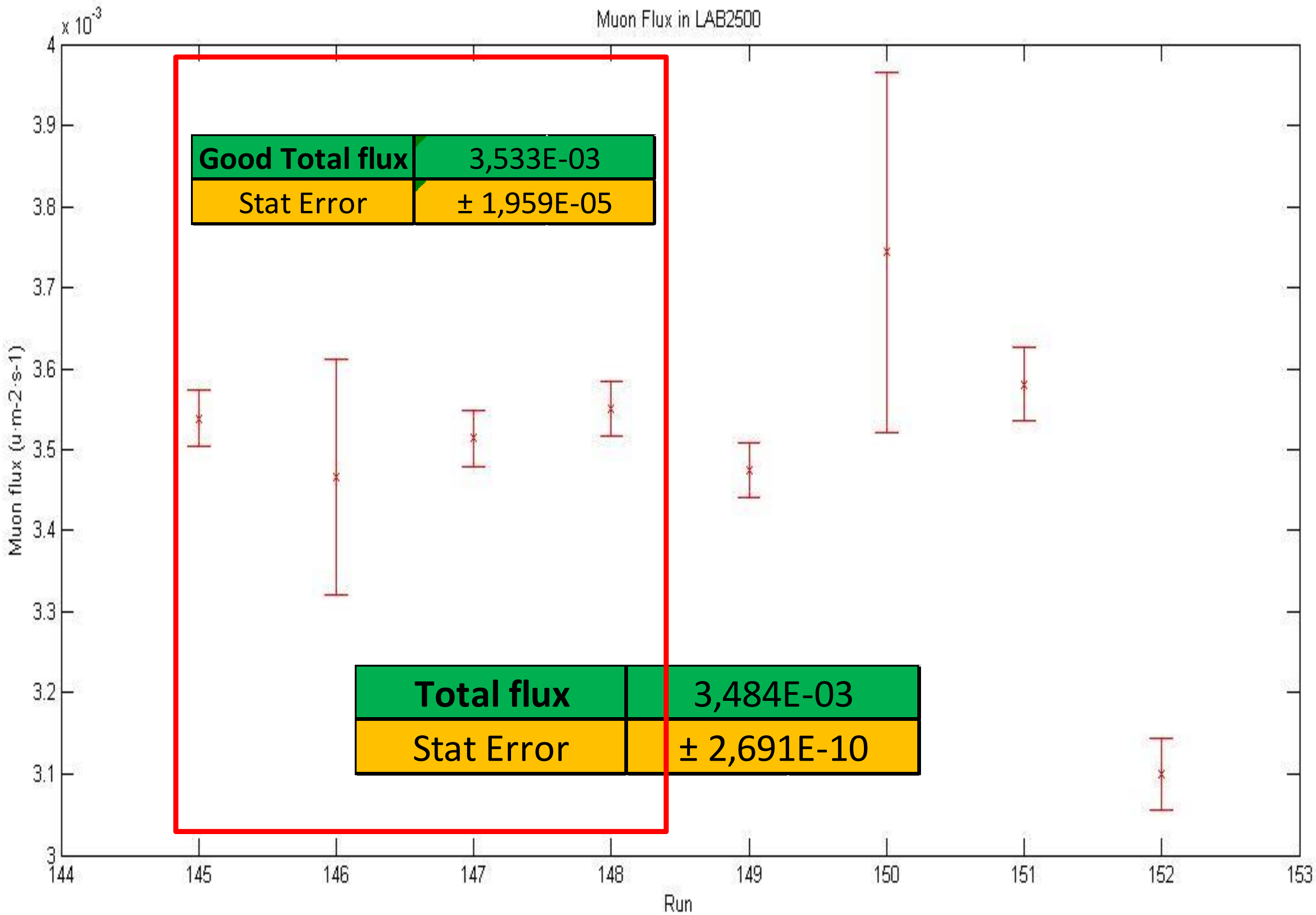


Measurement of absolute muon efficiency of the SC16 pixels using the additional scintillators. The four-fold coincidence: ***2 pixels of 2 different levels + AS1 +AS2*** *seems to be muon event. If so, we can count absences of fits for the 3-d level pixel which can be hit by muon but has not been.*

Results – LAB2500



Results – LAB2500

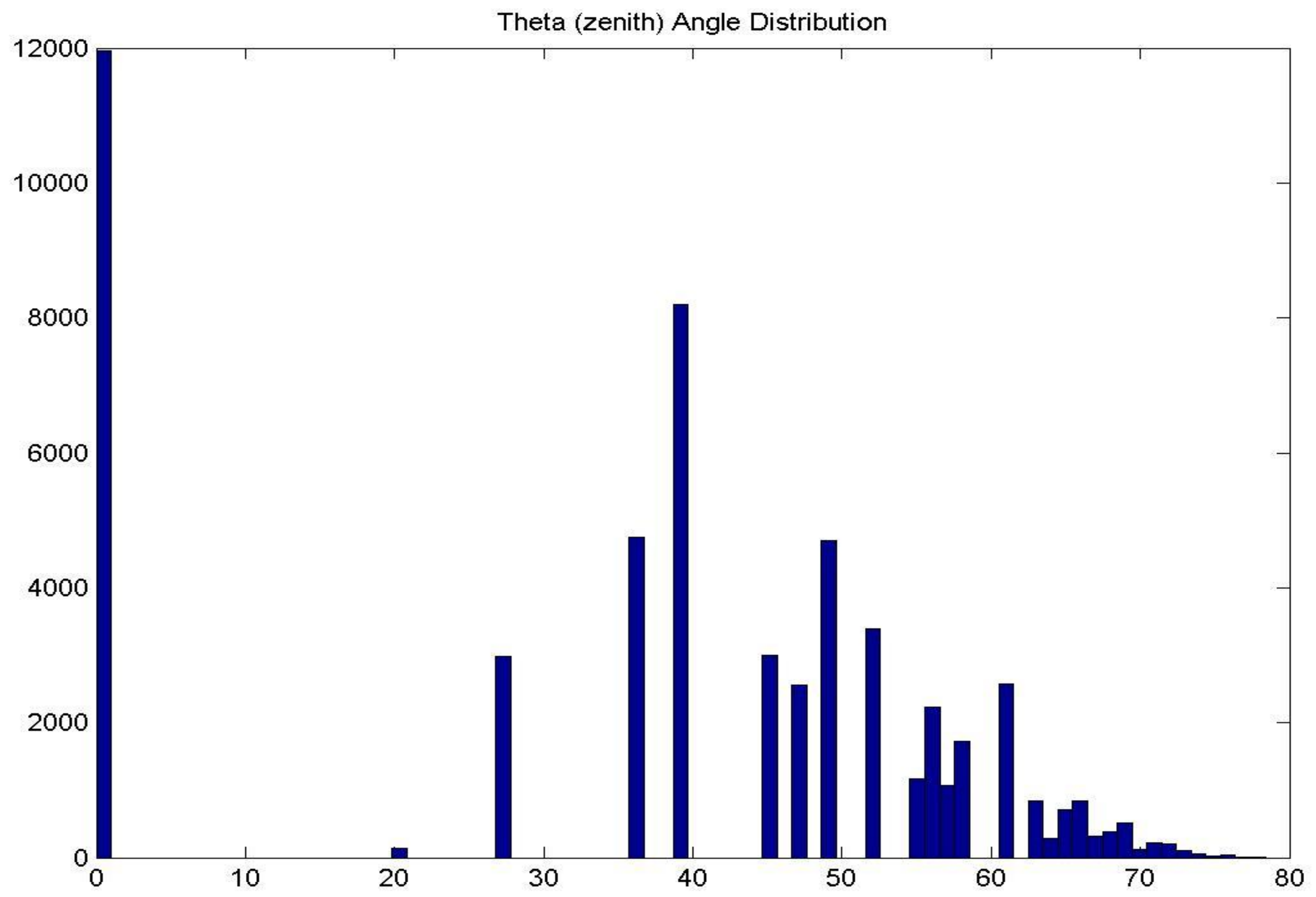


Good Total flux	3,533E-03
Stat Error	± 1,959E-05

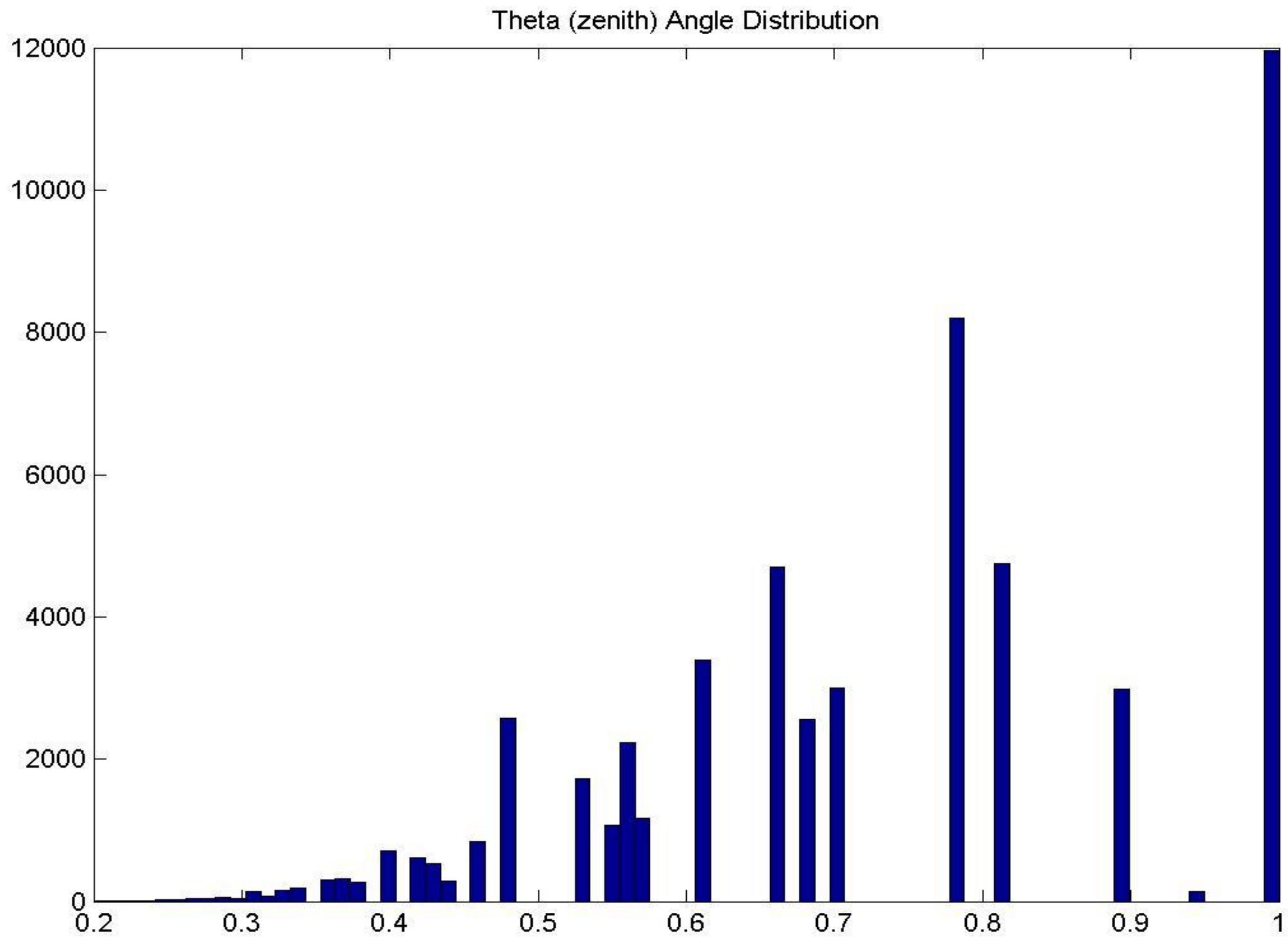
Total flux	3,484E-03
Stat Error	± 2,691E-10

Around 183 days of “good” data

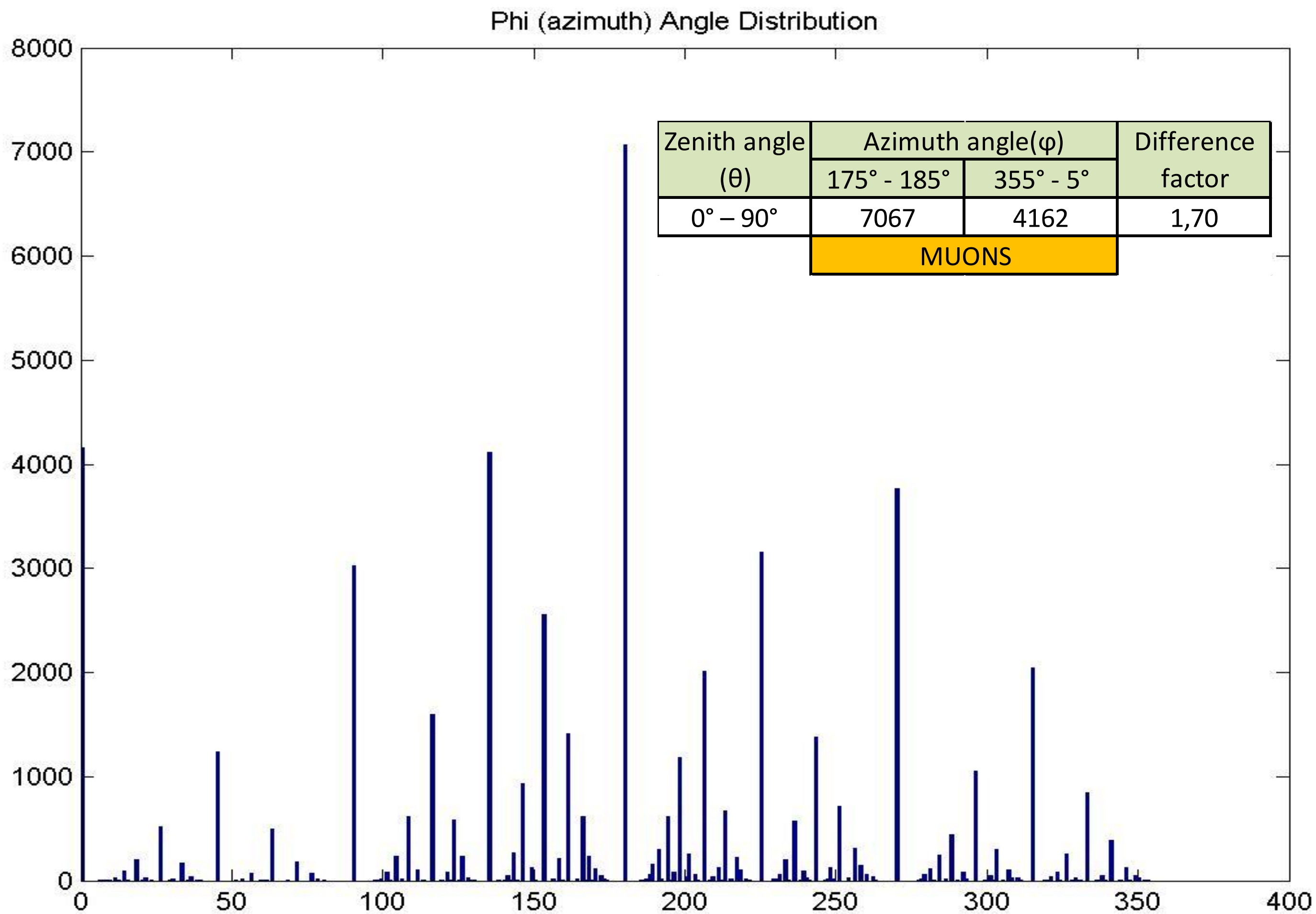
Results – LAB2500



Results – LAB2500

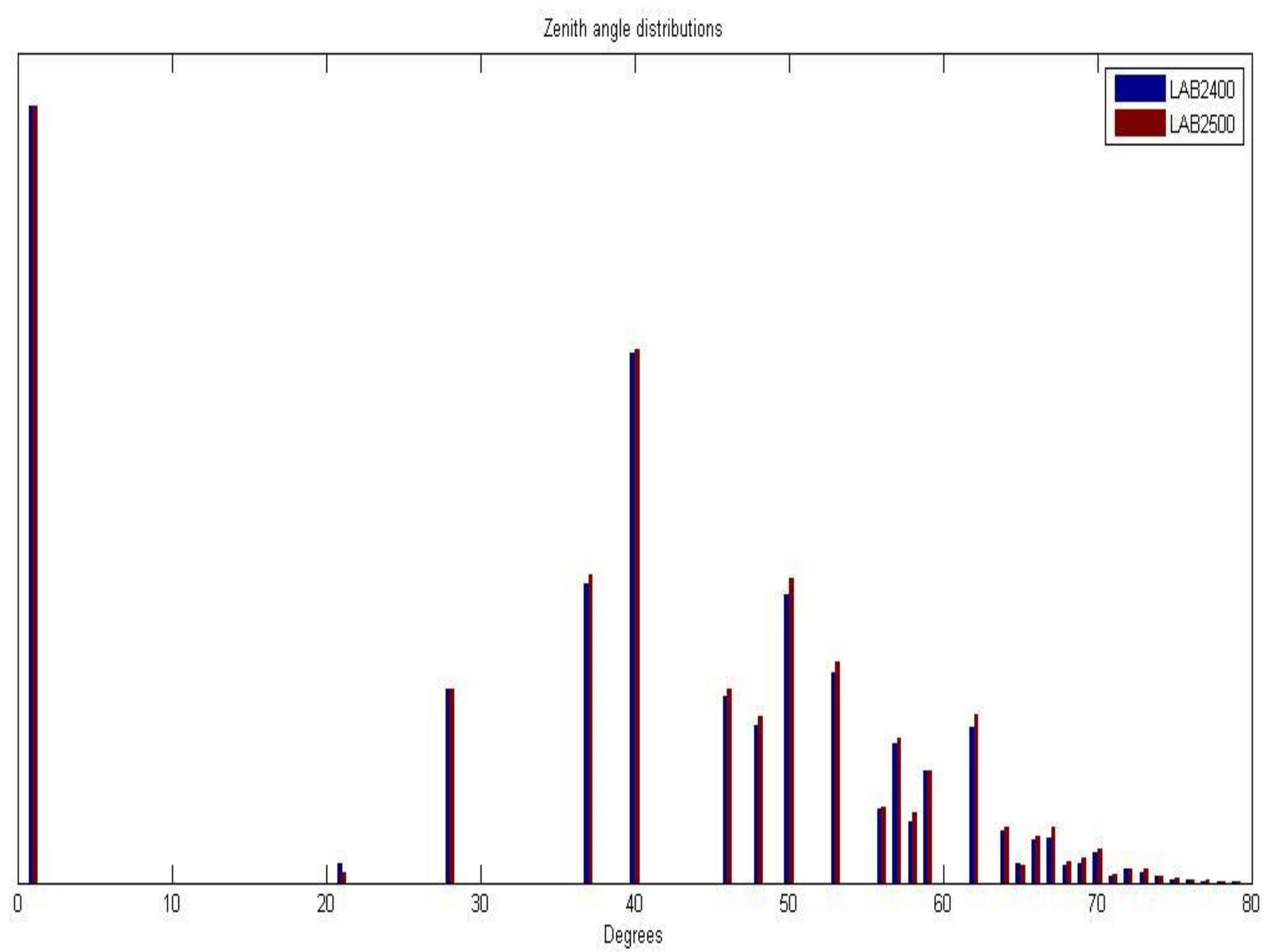


Results – LAB2500

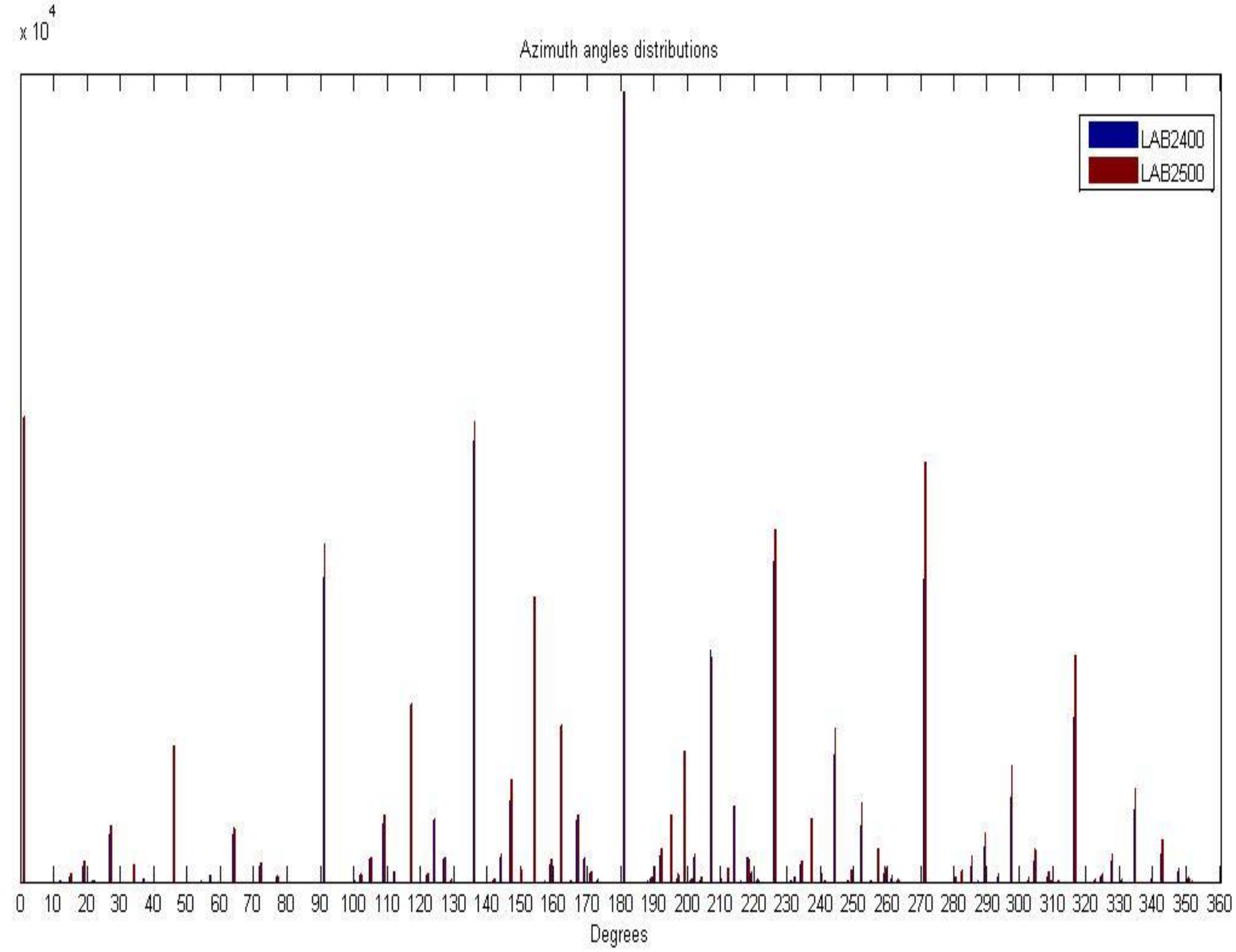


Zenith angle (θ)	Azimuth angle(φ)		Difference factor
	175° - 185°	355° - 5°	
0° – 90°	7067	4162	1,70
	MUONS		

Results


Zenith angle distributions
LAB2400
LAB2500
0
10
20
30
40
50
60
70
80
Degrees

Results



x 10^4
Azimuth angles distributions
LAB2400
LAB2500
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360
Degrees

Conclusions

- ✓ We have made a muon monitor for underground measurement which is sensitive, precise and reliable.
- ✓ We have enough data to obtain a good statistic value
- ✓ The value measured is similar to the expected
- ✓ We observe the dependence between muon flux and mountain profile
- ✓ The gaps observed in the angles distribution is related with the pixel gap

To do....

- Geometry Monte Carlo simulation can correct the final value
- This final value must be similar to plastics scintillator corrected (surface and gap calibration) value
- We could include the date and time in the program in order to check the modulation
- Could be interesting make a program similar to used to check the final values
- The monitor data can be applied for tomography of LSC overburden

Status of the muon measurement in LSC

Thank you for attention!!