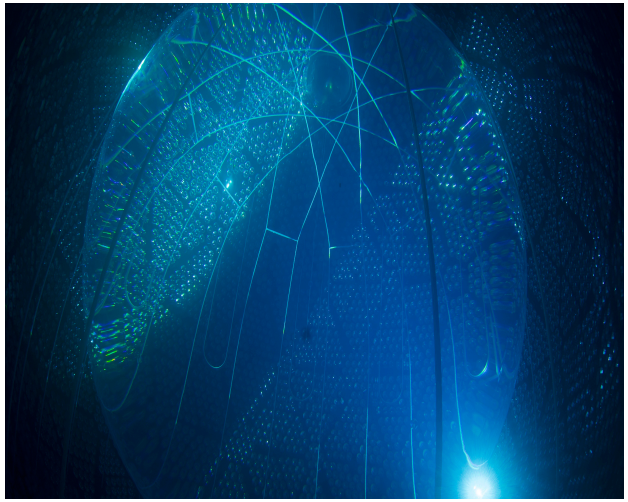
K40 BACKGROUNDS IN THE SNO+ NEUTRINO DETECTOR

Parmesh Ravi

The SNO+ experiment:-

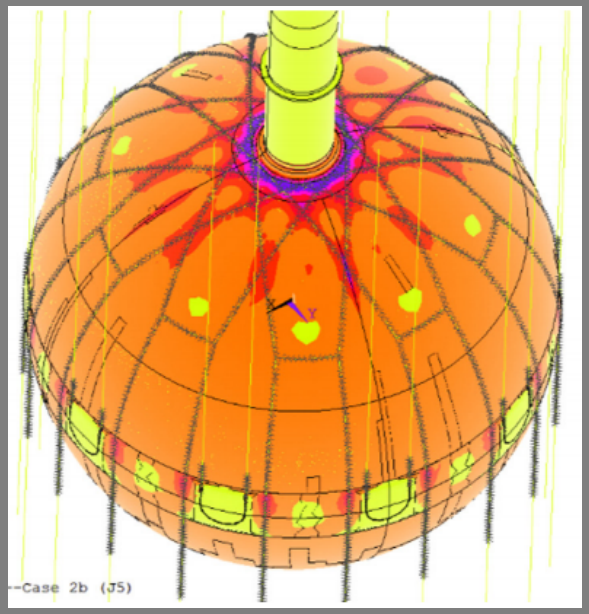
- Deep underground neutrino detector at SNOLAB… goal: search for 0vbb… high sensitivity.
- K40 is a crucial background to deal with in a neutrino detector (high half life, spectral overlap)
- Approaches usually involve guesses/ elimination tactics
- We exploit the structure of SNO+ to pinpoint the K40 signal.



SNO+ Neutrino Detector

Ropes of the SNO+ detector:-

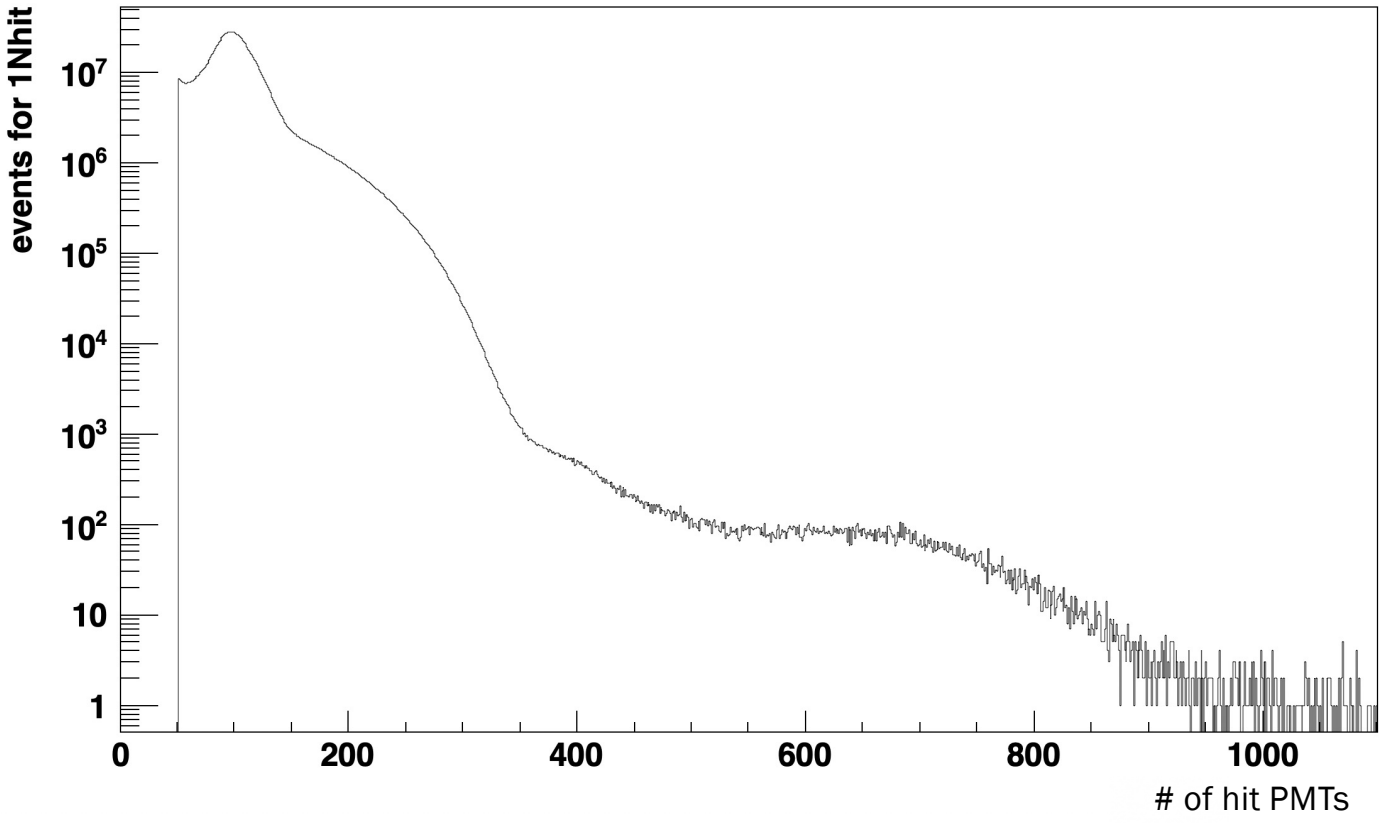
- Detector has a large Vessel—held in place by Hold down ropes
- *Ropes contain more K40 than the surrounding material* [1]
- *We can use this fact to pinpoint the K40 signal.*



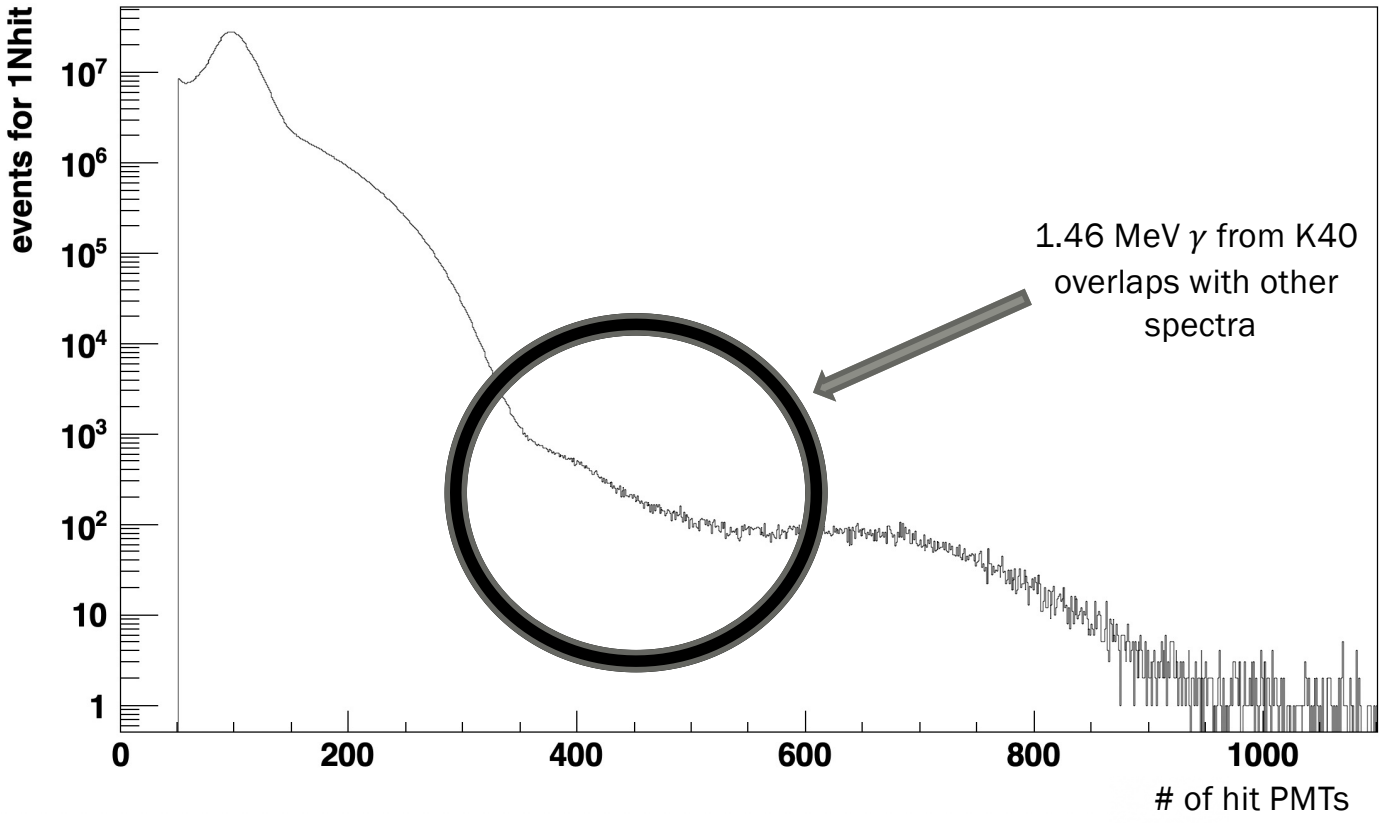
Schematic

[1] A. Bialek, et al., 2008, https://doi.org/10.1016/j.nima.2016.04.114

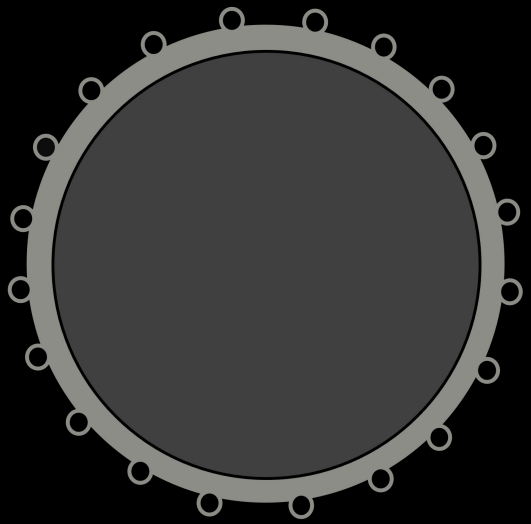
Data collected by the detector



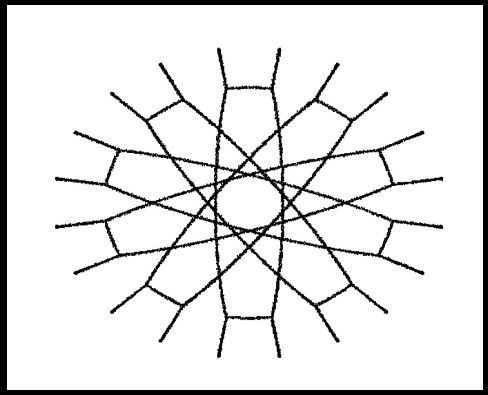
Data collected by the detector



The ropes have a periodic structure...



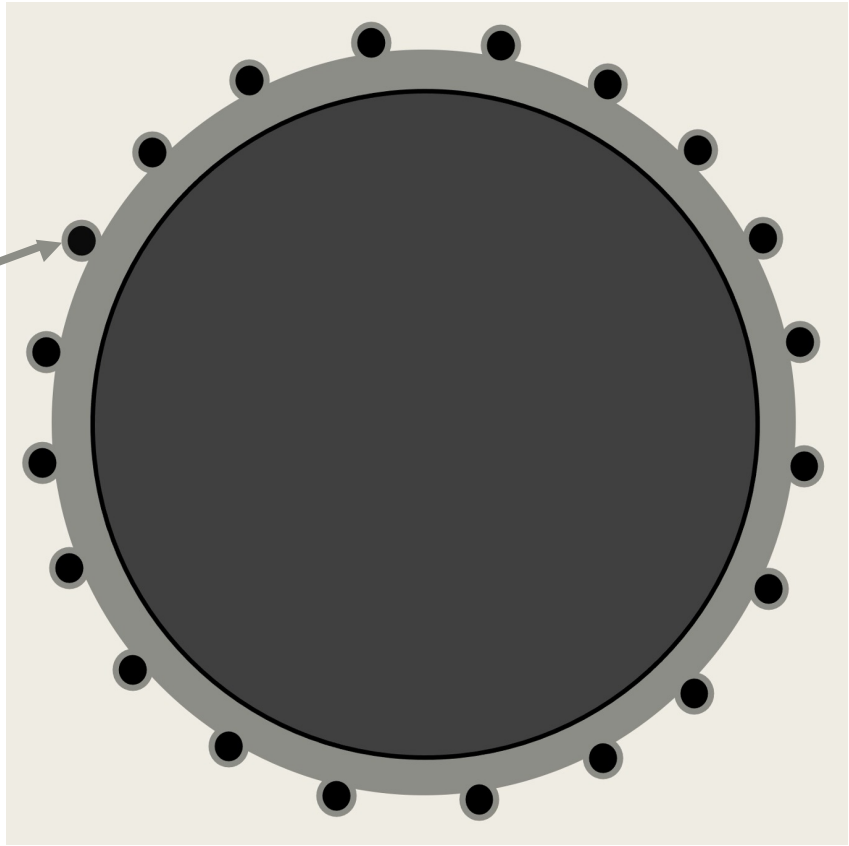
Cross-section



View from top

- 20 ropes total
- Distributed uniformly
- Spaced by 18 °

Hold Down ropes
(in the cross section)



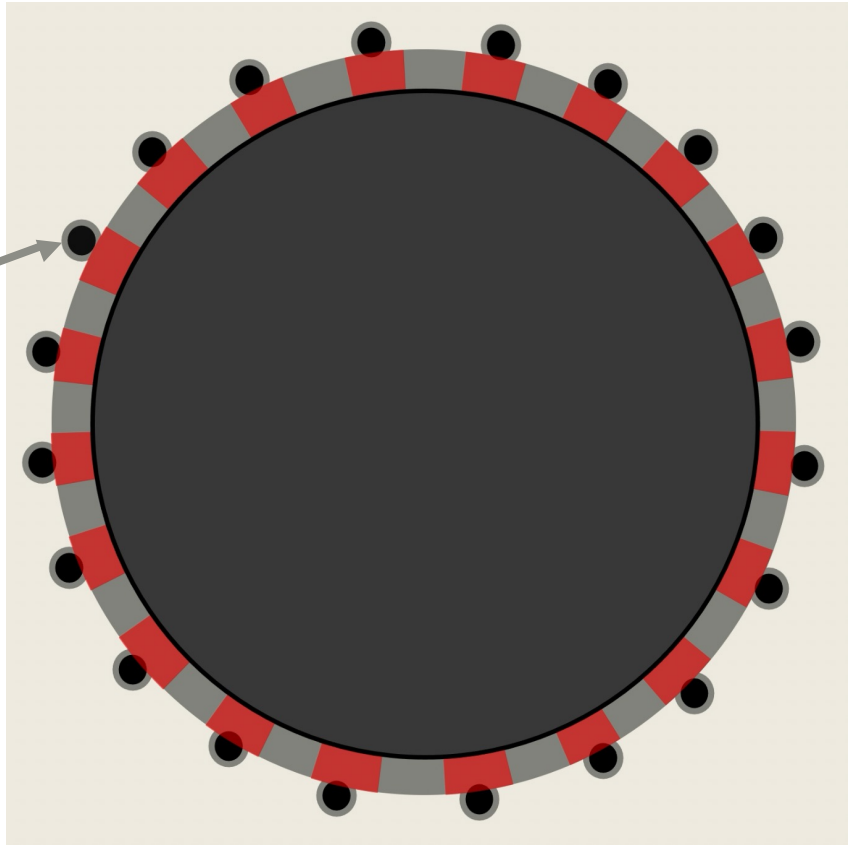
- HDR Dominant
- HDR Free

Optimal cuts:-

r > 5200 mm

3° Az. per section

Hold Down ropes
(in the cross section)



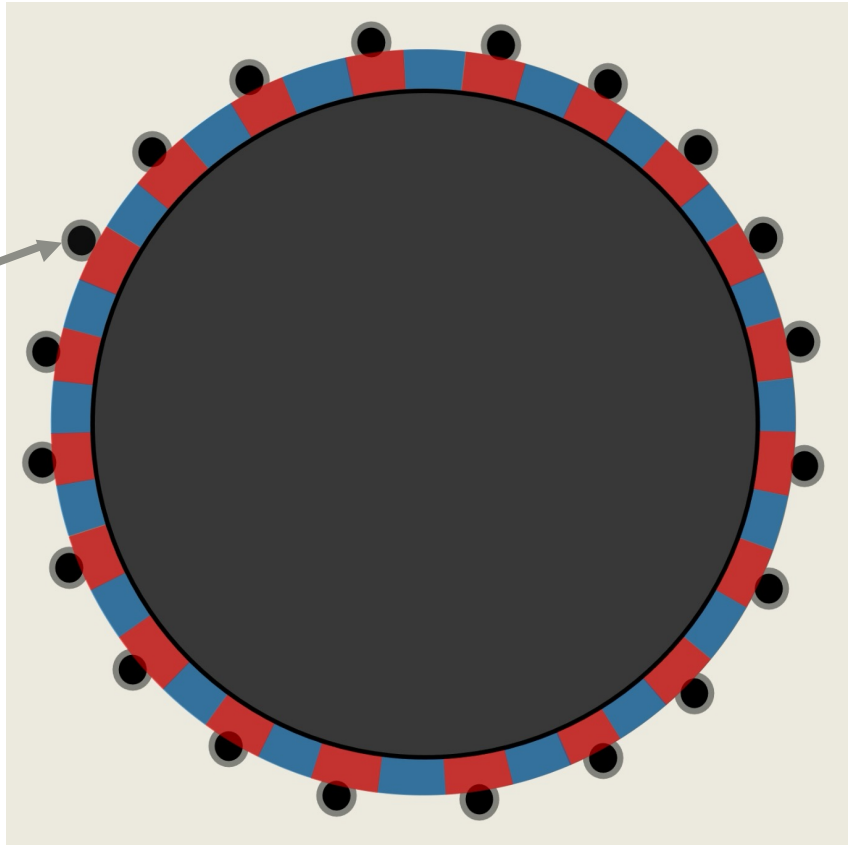
- HDR Dominant
- HDR Free

Optimal cuts:-

r > 5200 mm

3° Az. per section

Hold Down ropes
(in the cross section)



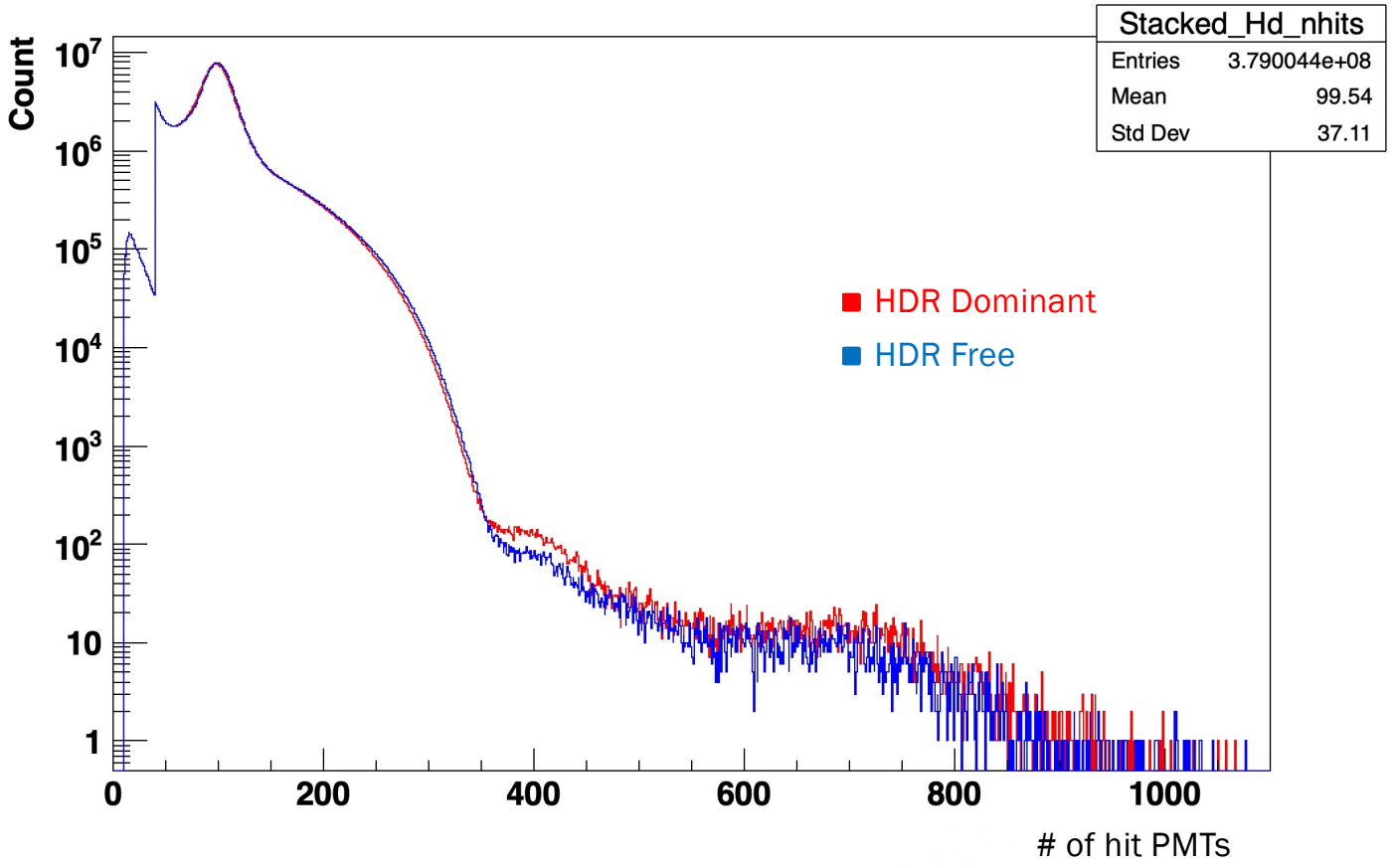
- HDR Dominant
- HDR Free

Optimal cuts:-

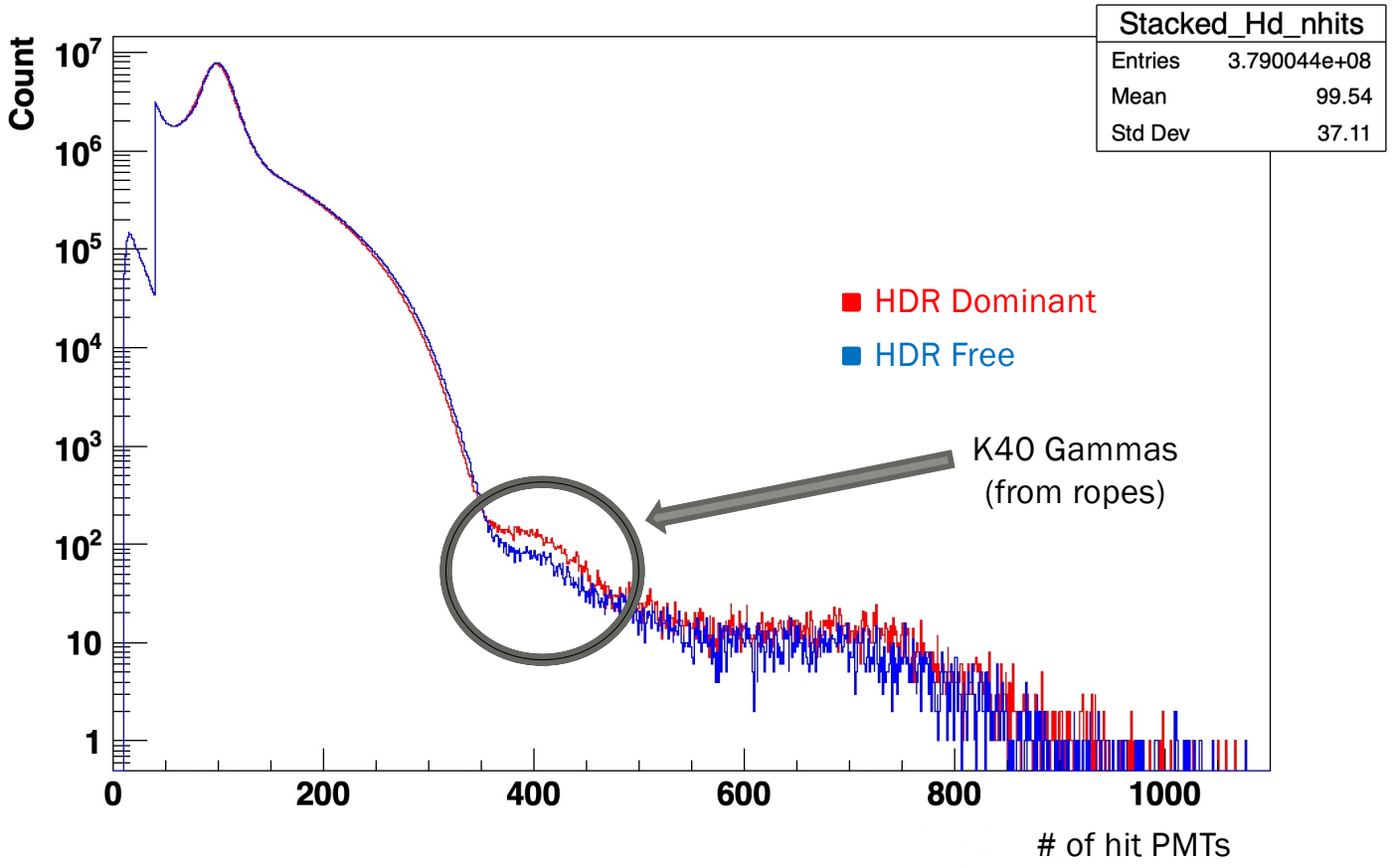
r > 5200 mm

3° Az. per section

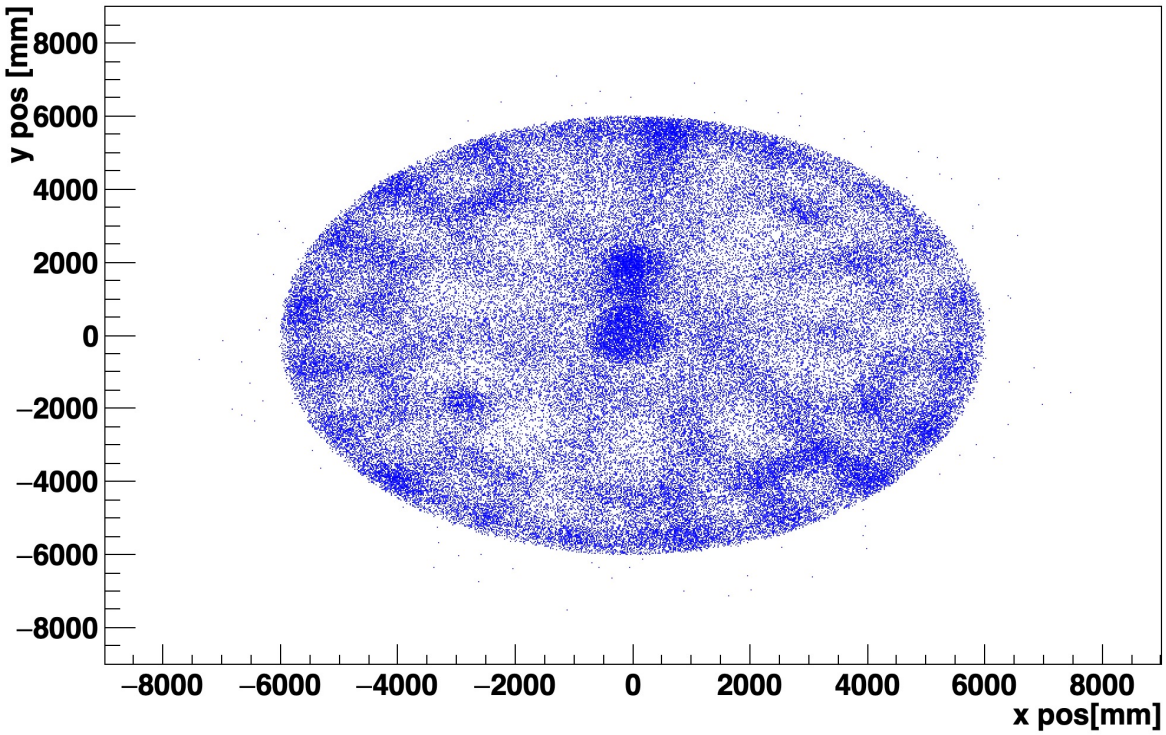
Ang. Width = 3


Stacked_Hd_nhits
Entries 3.790044e+08
Mean 99.54
Std Dev 37.11
Count
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
# of hit PMTs
HDR Dominant
HDR Free

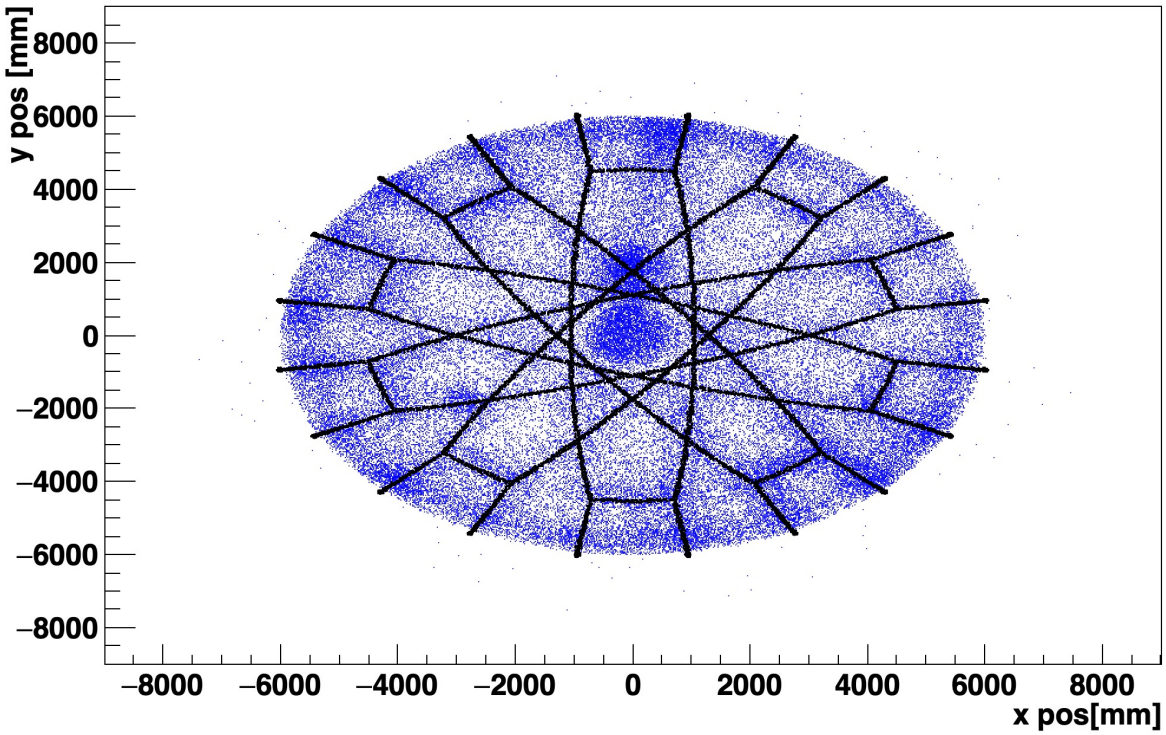
Ang. Width = 3


Stacked_Hd_nhits
Entries 3.790044e+08
Mean 99.54
Std Dev 37.11
Count
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
# of hit PMTs
HDR Dominant
HDR Free
K40 Gammas
(from ropes)

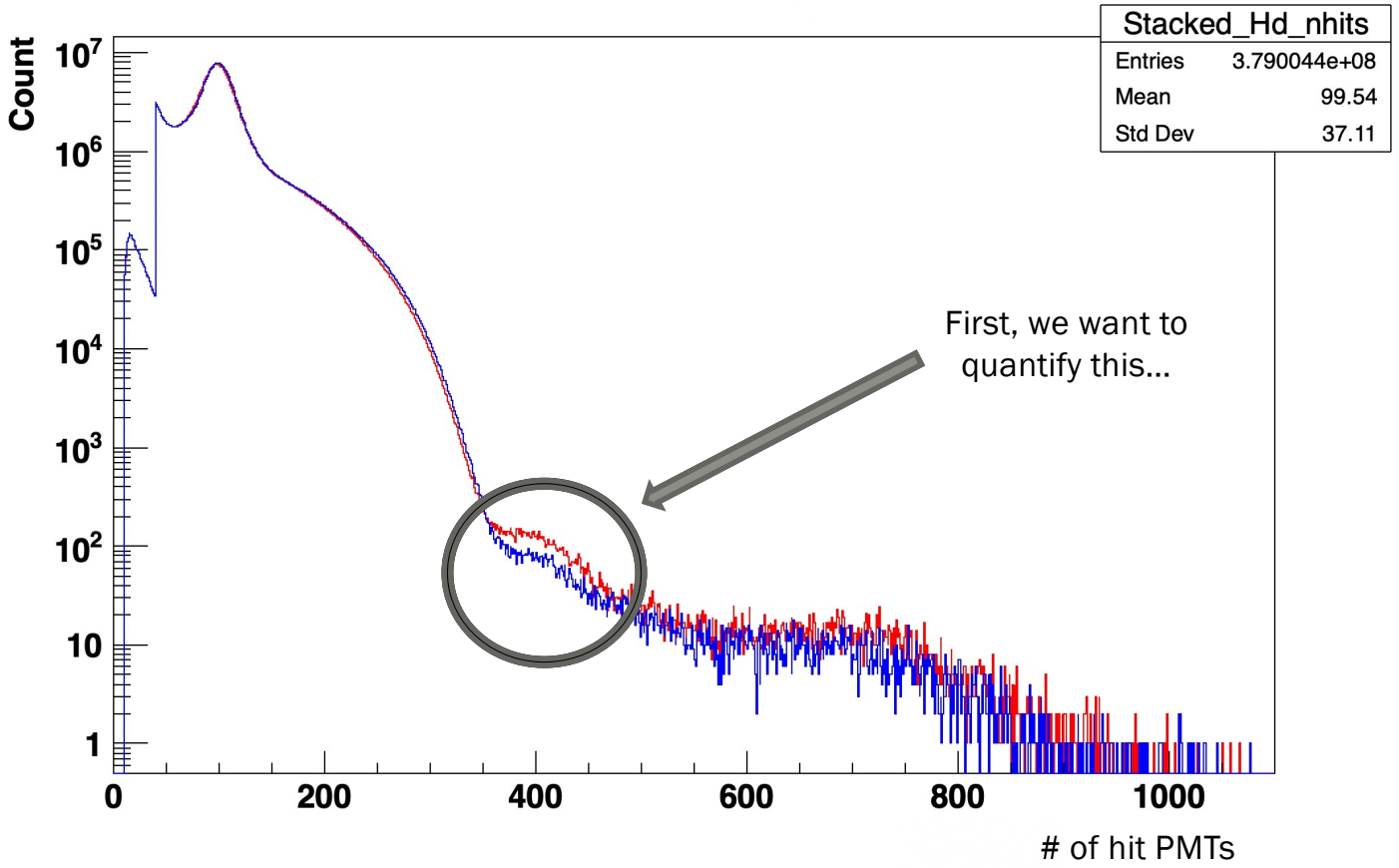
Ropes active region (370 – 450 nhits)

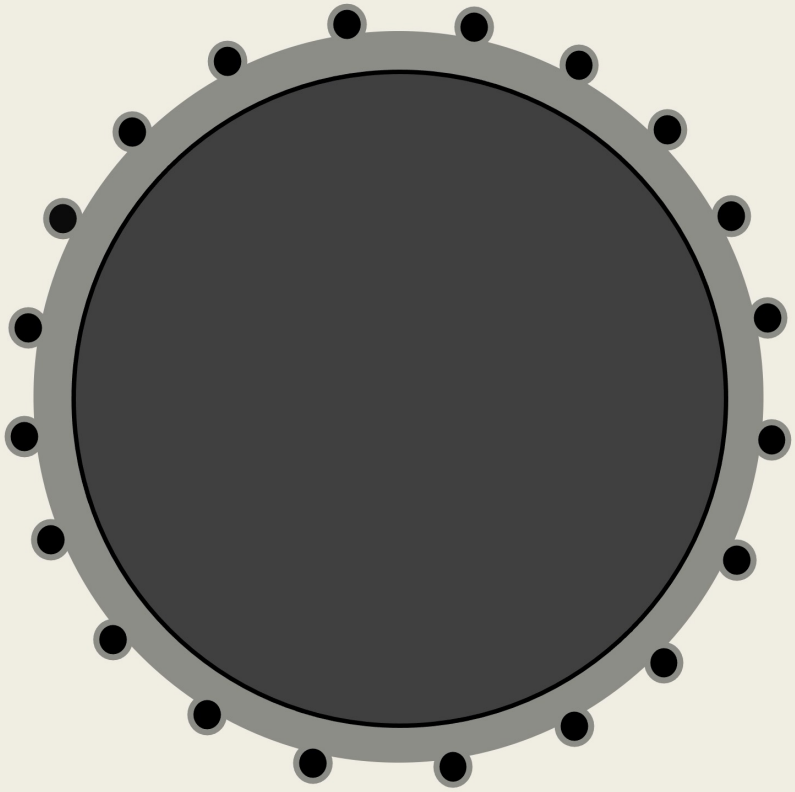


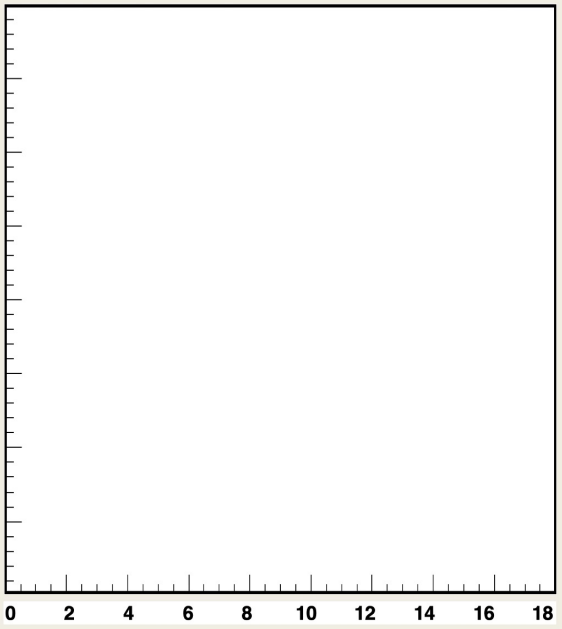
Ropes active region (370 – 450 nhits)

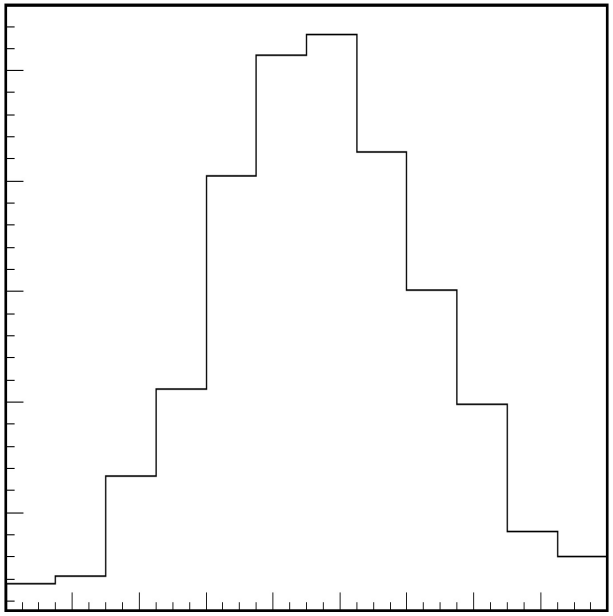


Ang. Width = 3


Stacked_Hd_nhits
Entries 3.790044e+08
Mean 99.54
Std Dev 37.11
Count
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
# of hit PMTs
First, we want to quantify this…




0
2
4
6
8
10
12
14
16
18



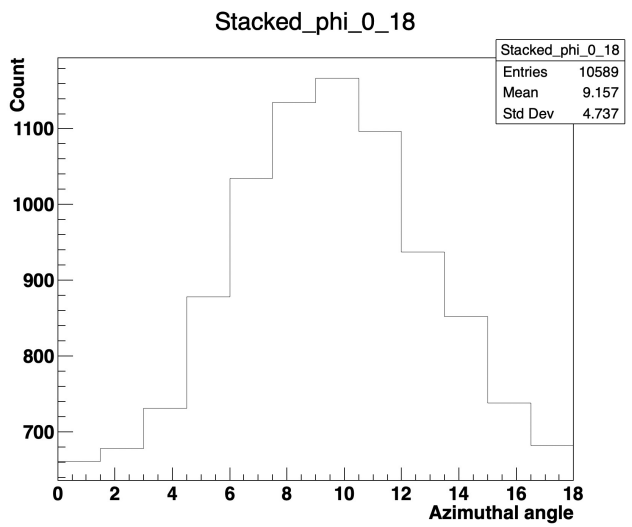
With ~ 27 Days of August data

Processing to Compute
BL rem. Integral

Modified derivation yields
measure of HDR exclusive K40 gammas

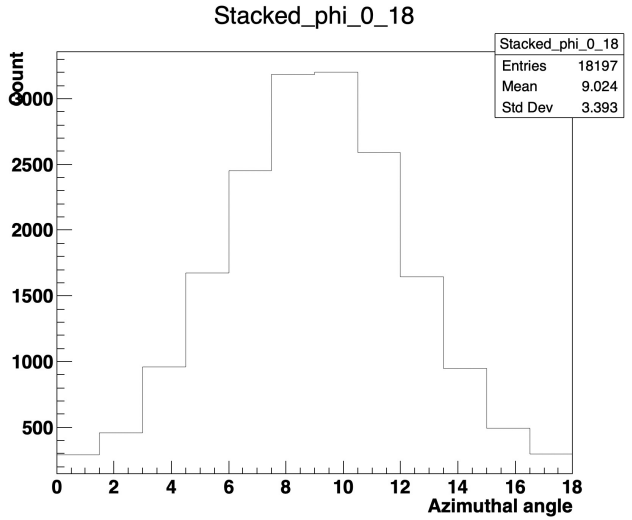
Events = 2312 ± 147

Data



BL removed Integral = 2312

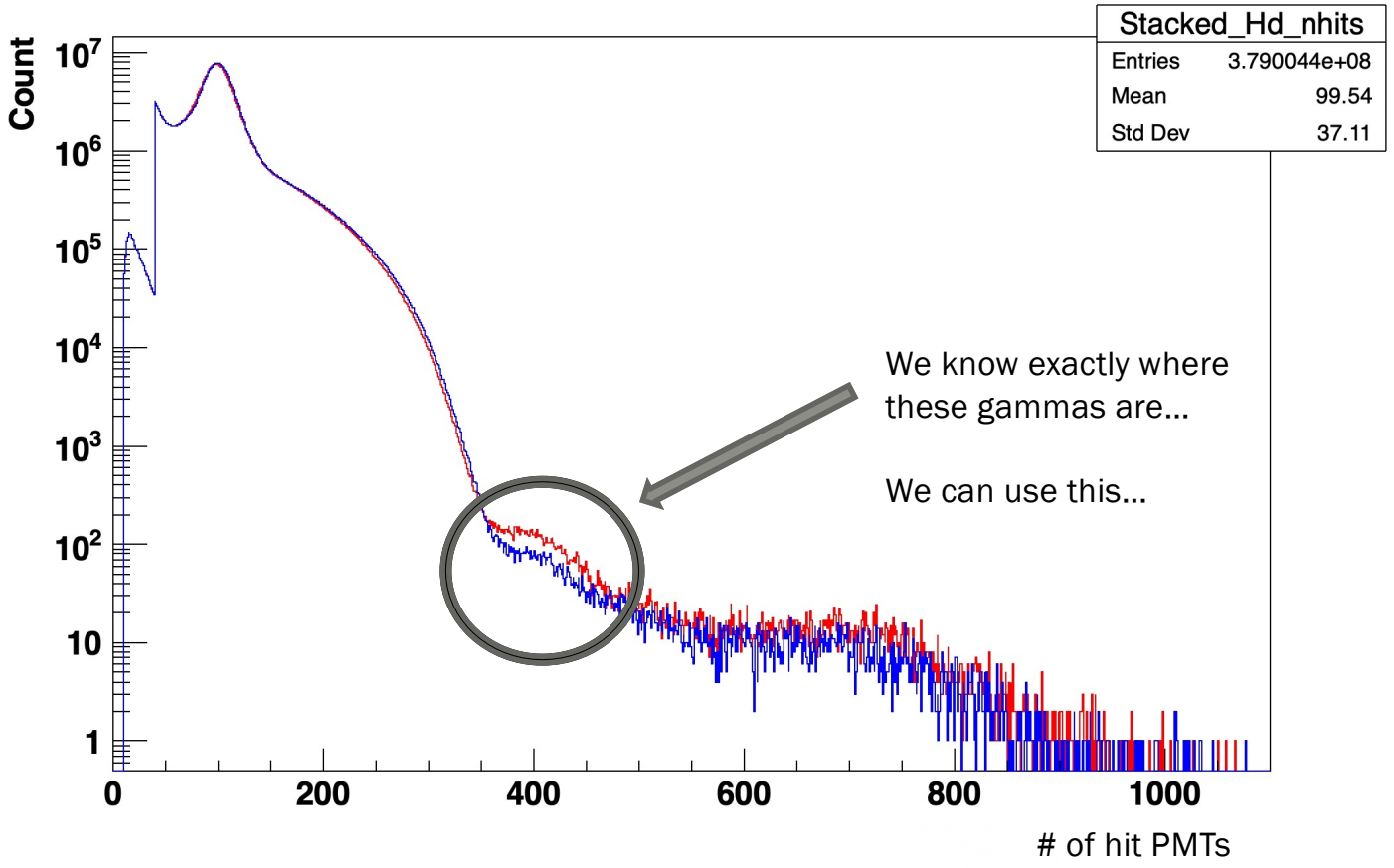
MC



BL removed Integral = 13405

i.e. data/MC ~ 0.17

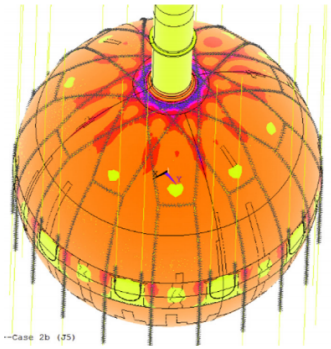
Ang. Width = 3


Stacked_Hd_nhits
Entries 3.790044e+08
Mean 99.54
Std Dev 37.11
Count
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
# of hit PMTs
We know exactly where these gammas are…
We can use this…

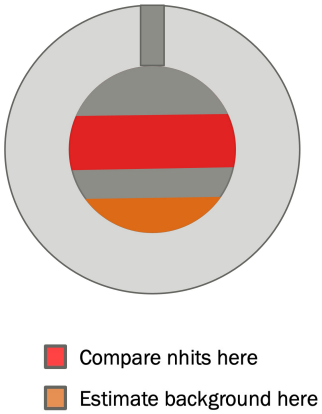
Application to Acrylic Vessel: -

- We can use this signal to characterize the K40 from the AV
- Compare nhits where ropes and AV occur in the same position radially
- **But, measure where ropes are away from the AV**

Yielding Data/MC Ratio = $\frac{19086}{118756} \sim 0.16$



AV and the ropes

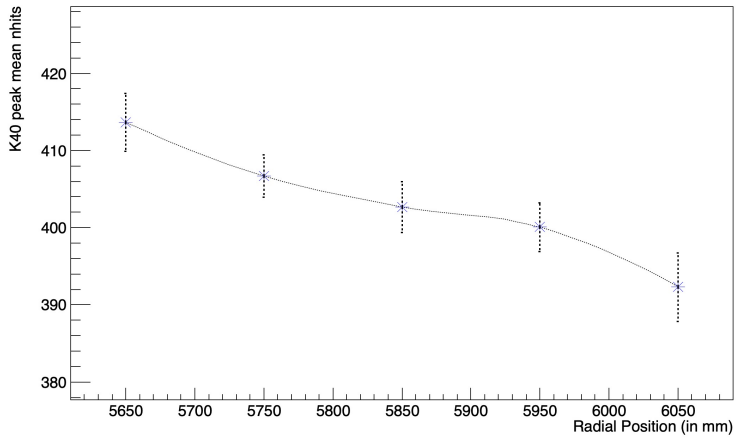


Dealing with Radial dependence of nhits

Application to Internal K40: -

- With internal K40 there's no easy way to deal with radial nhit dependence
- But, the gammas from the ropes penetrate a bit into the scintillator
- We can model this and extrapolate to interior.

This is what I'm working on currently…



Radial dependence of K40 signal

Summary of results:-

- Provides a way knowing exactly where the K40 signal manifests in SNO+

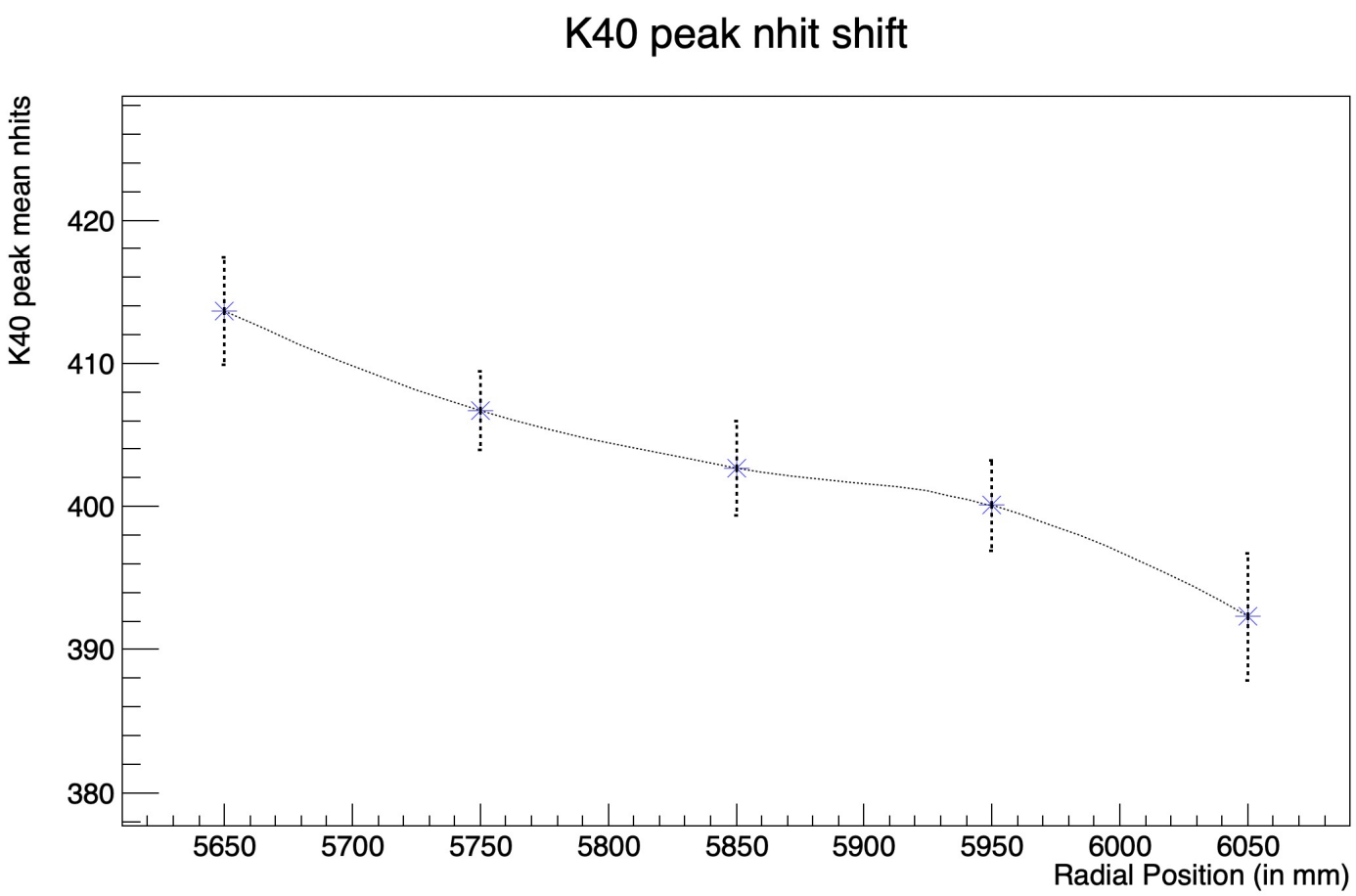
- This measurement has been used to characterize and quantify the K40 background from several sources: ropes, AV, now scintillator…

- Because of the high half life of K40 decays, this signal can be used as an option to calibrate the detector or monitor light yield

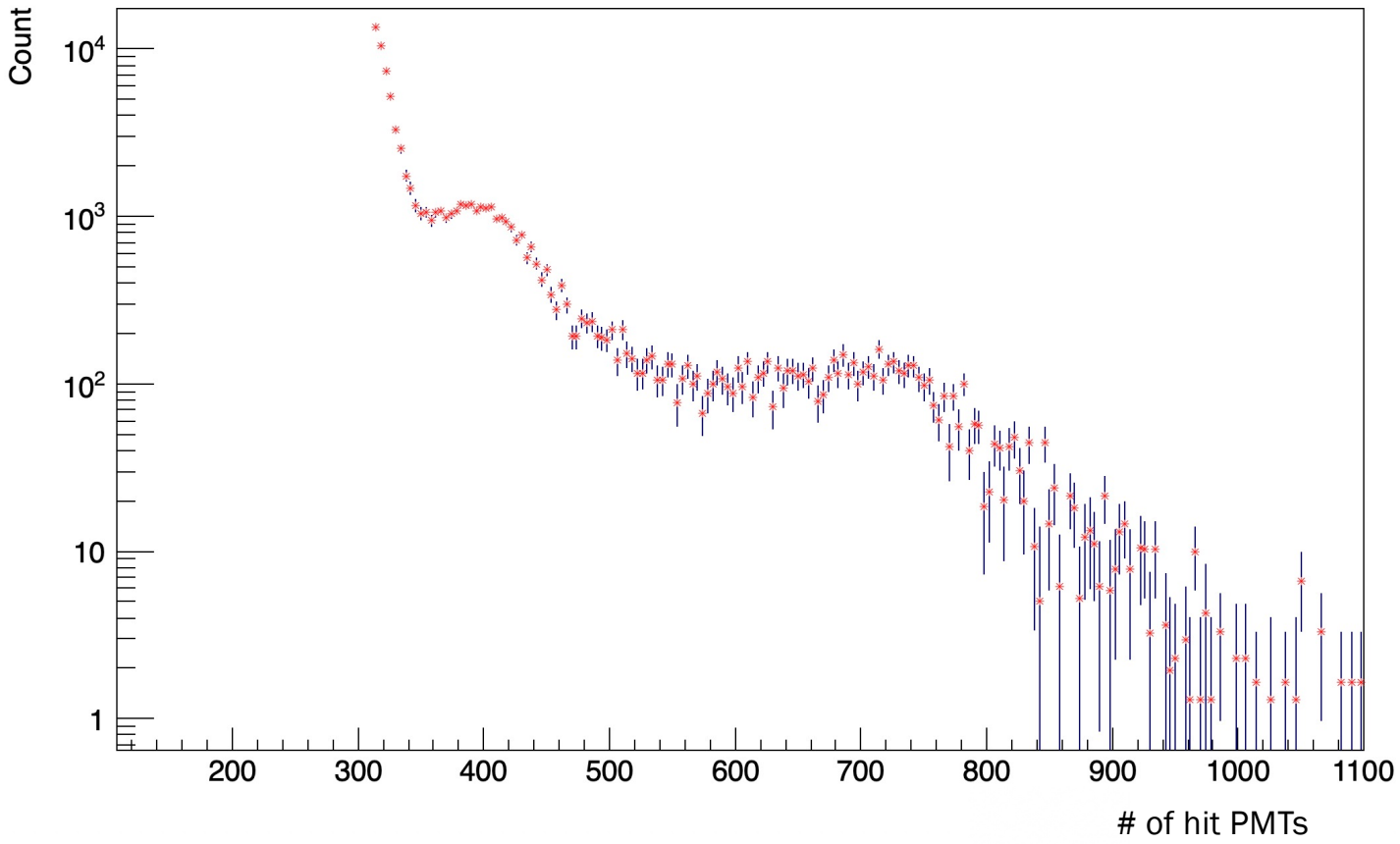
QUESTIONS, COMMENTS CLARIFICATIONS?

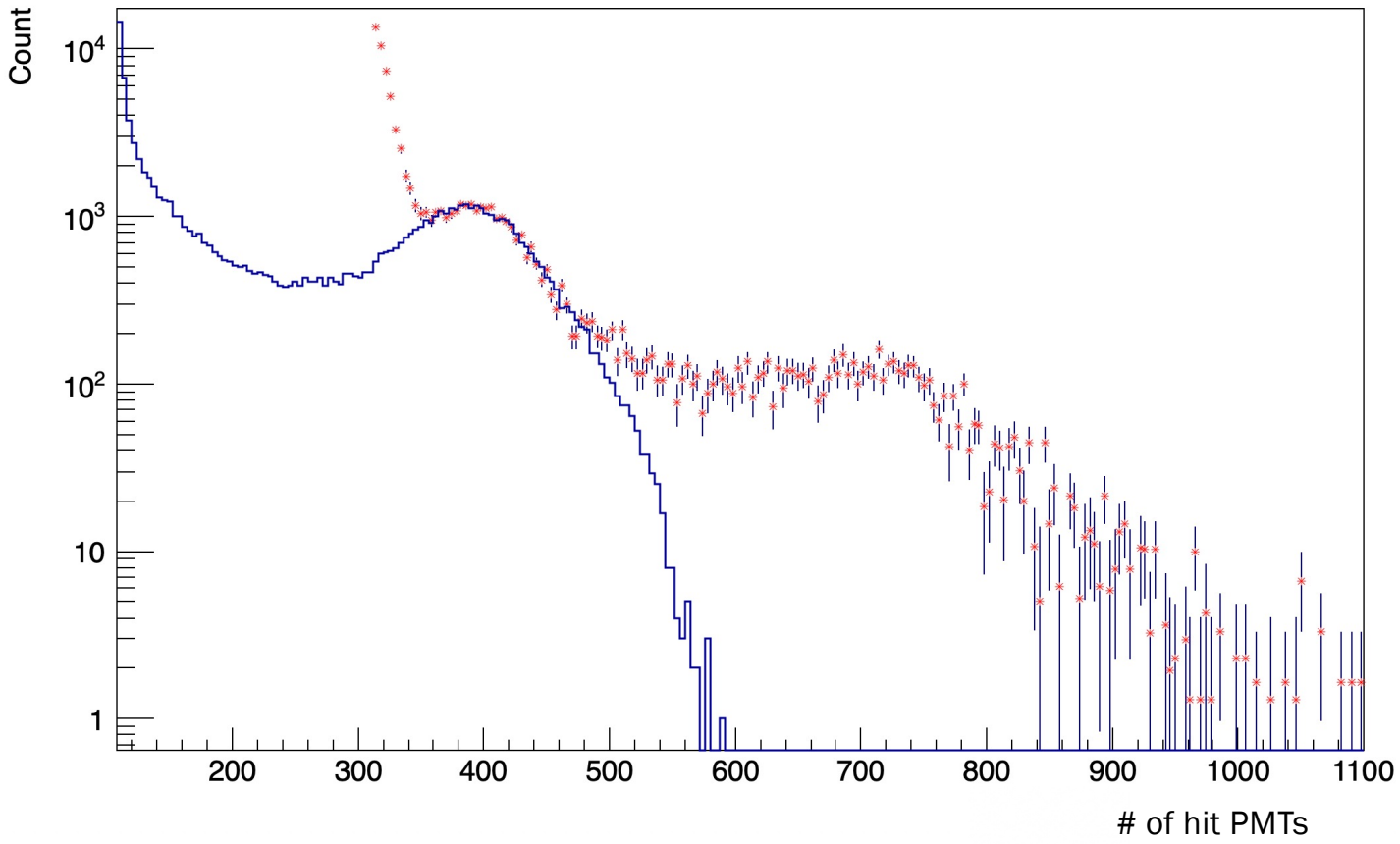
BACKUP SLIDES

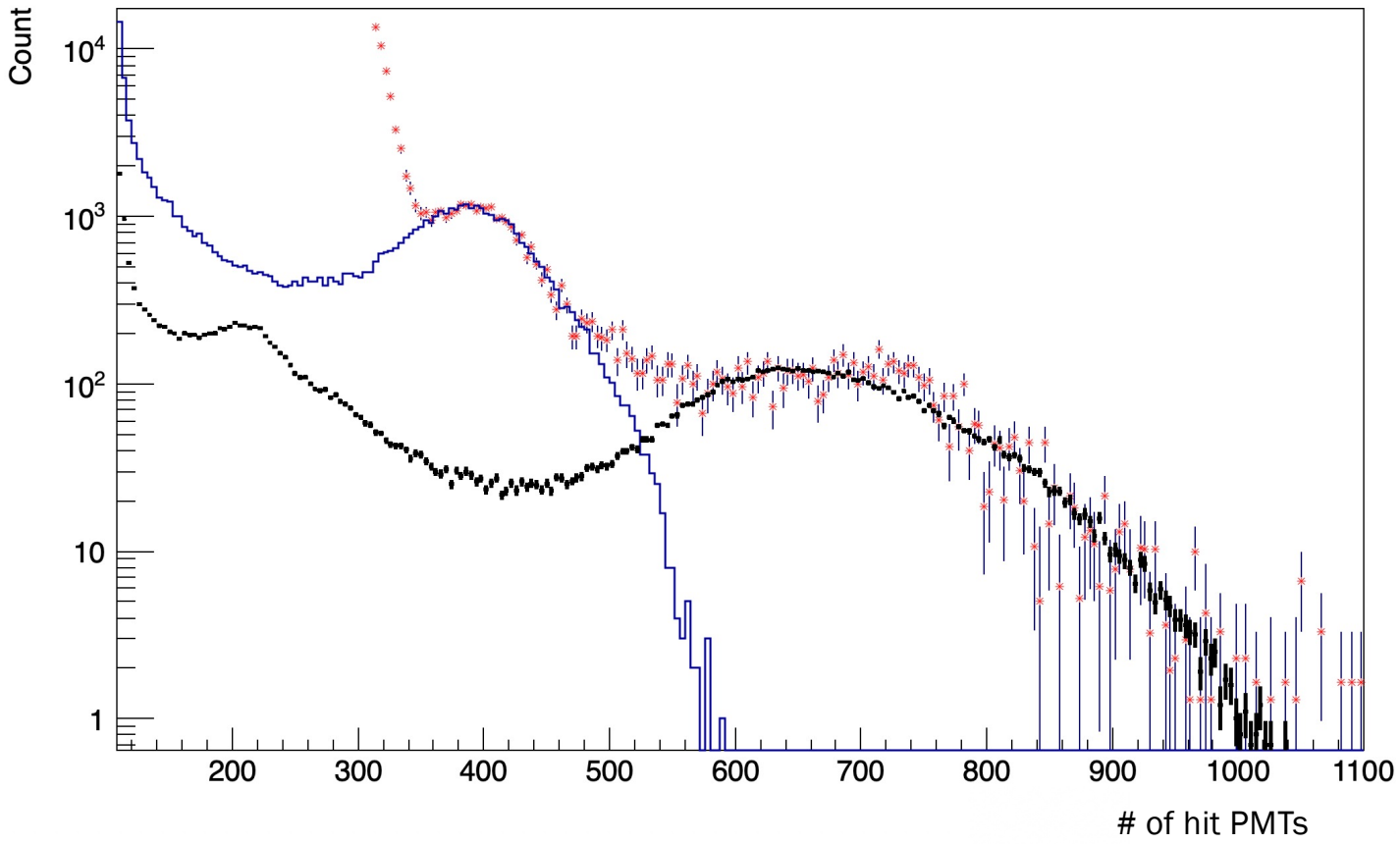
K40 NHIT SHIFT:-

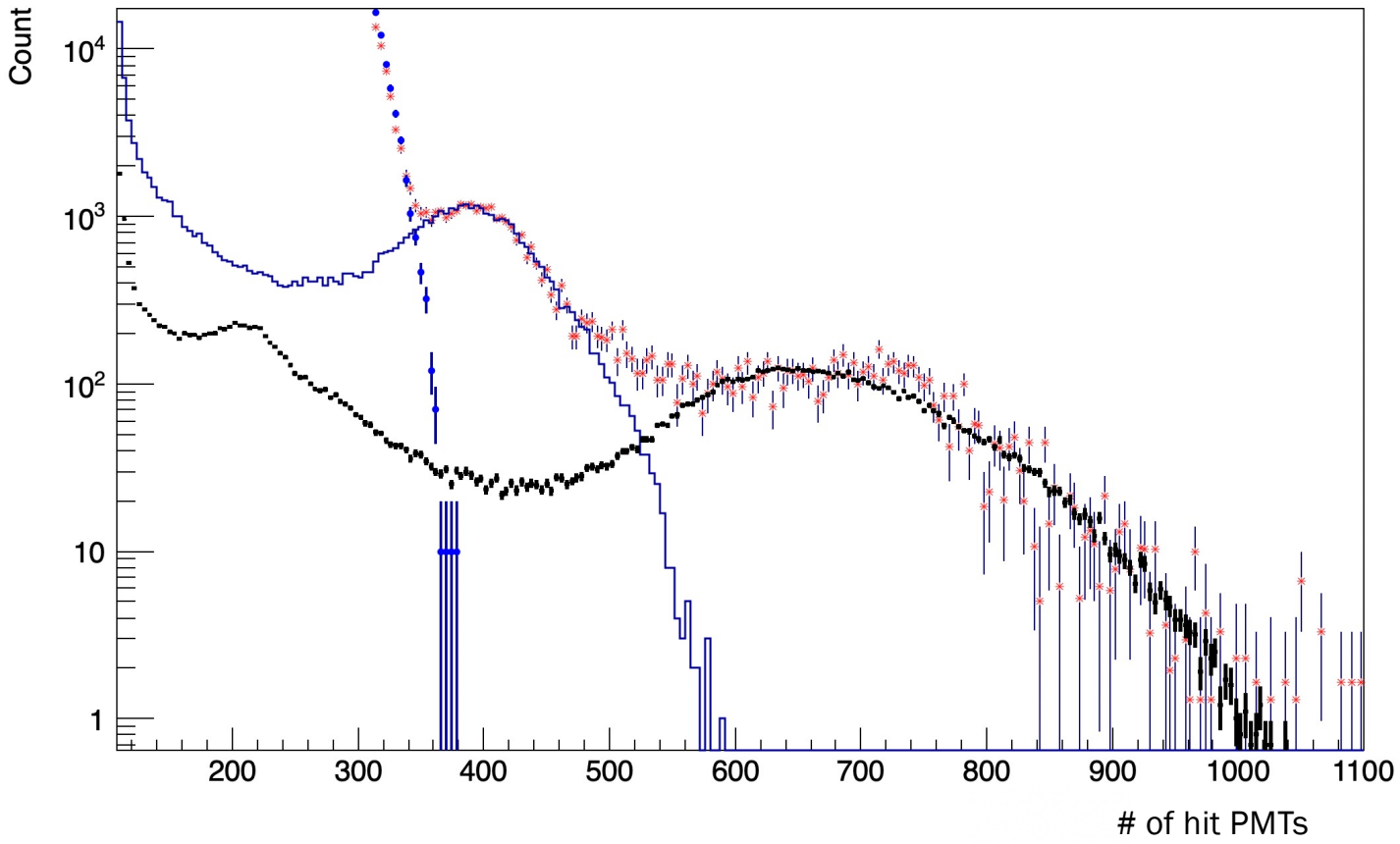

K40 peak nhit shift
K40 peak mean nhits
420
410
400
390
380
5650
5700
5750
5800
5850
5900
5950
6000
6050
Radial Position (in mm)

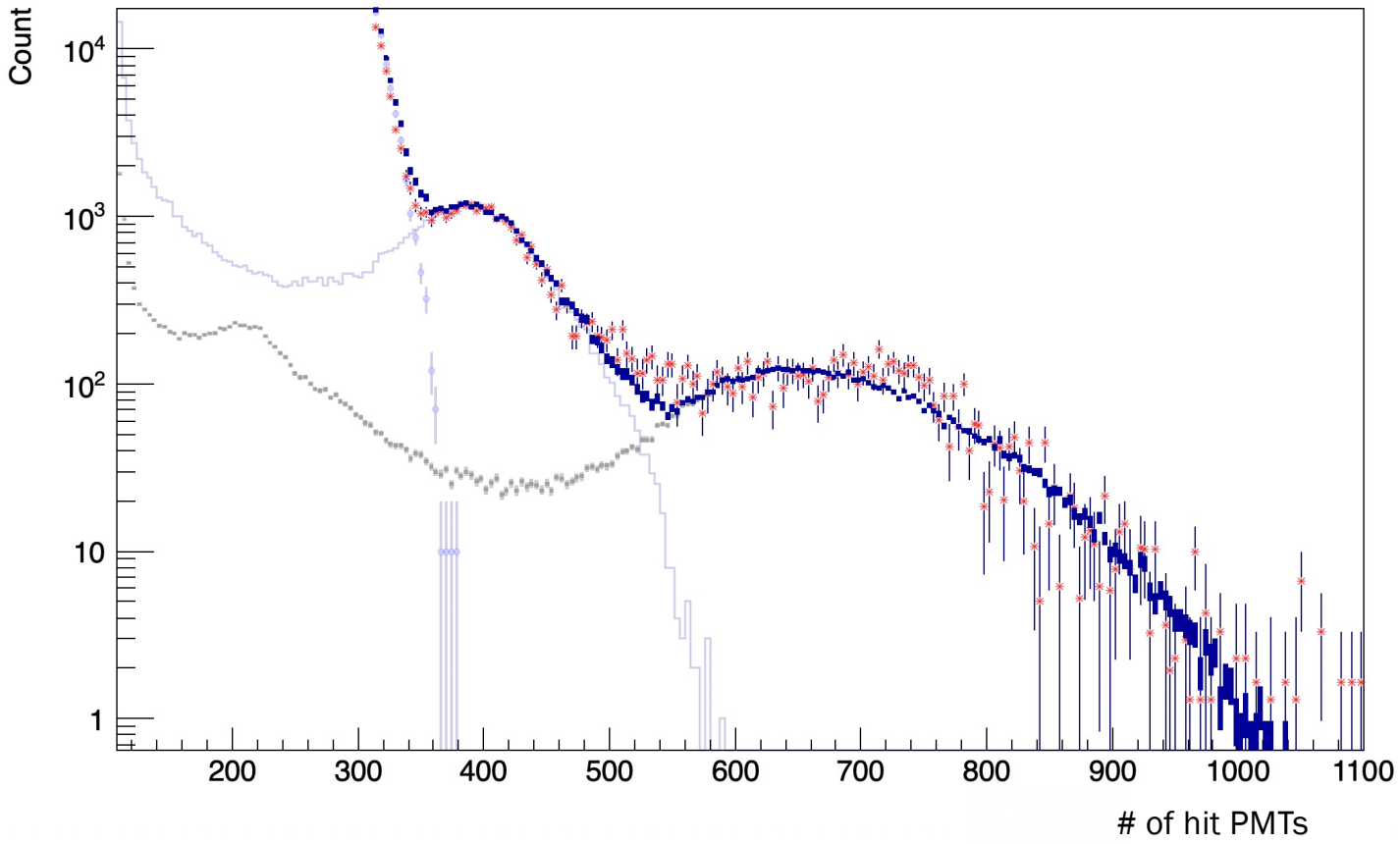
MC ALIGNMENT:-


Count
10^4
10^3
10^2
10
1
200
300
400
500
600
700
800
900
1000
1100
# of hit PMTs

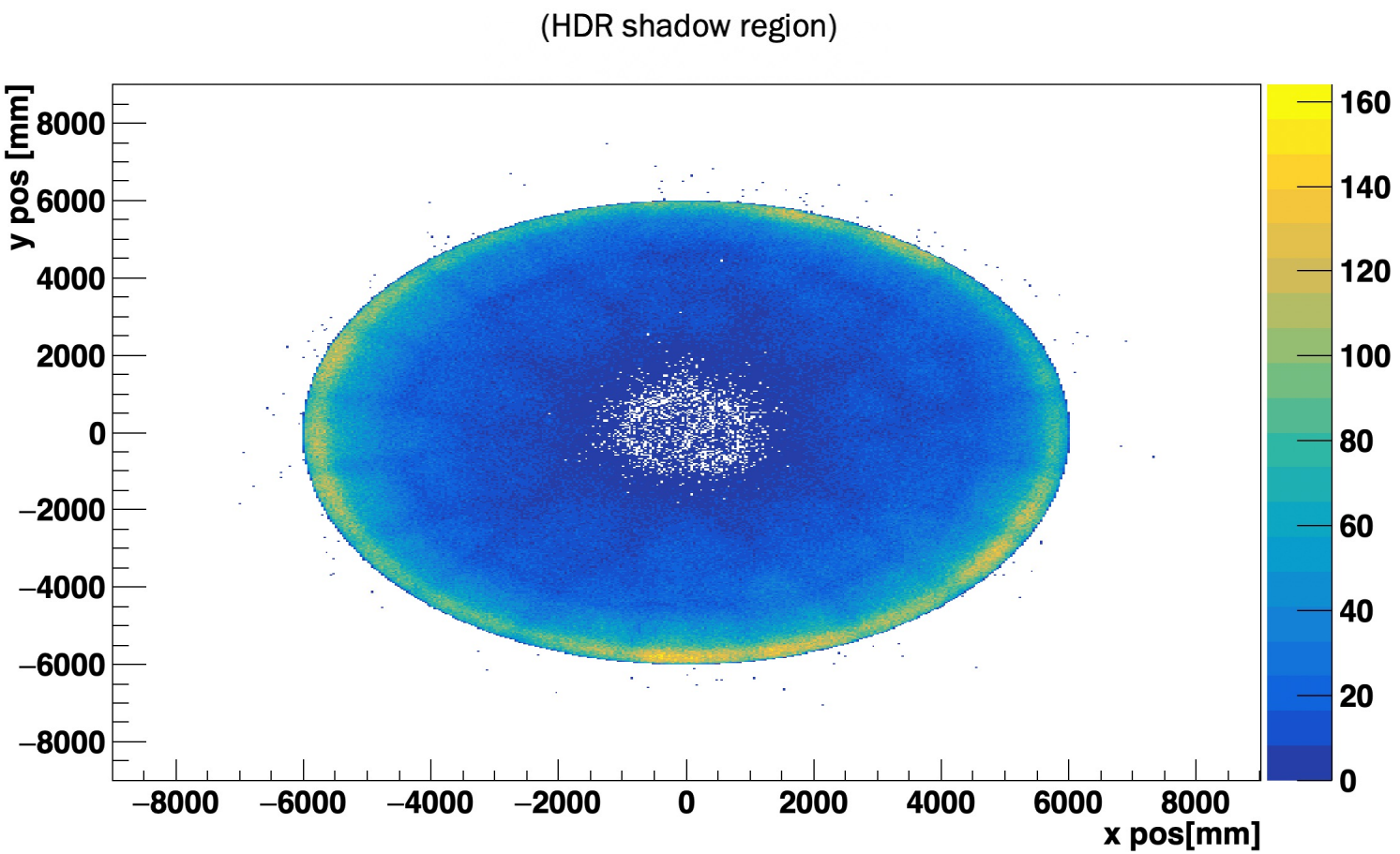

Count
10^4
10^3
10^2
10
1
200
300
400
500
600
700
800
900
1000
1100
# of hit PMTs

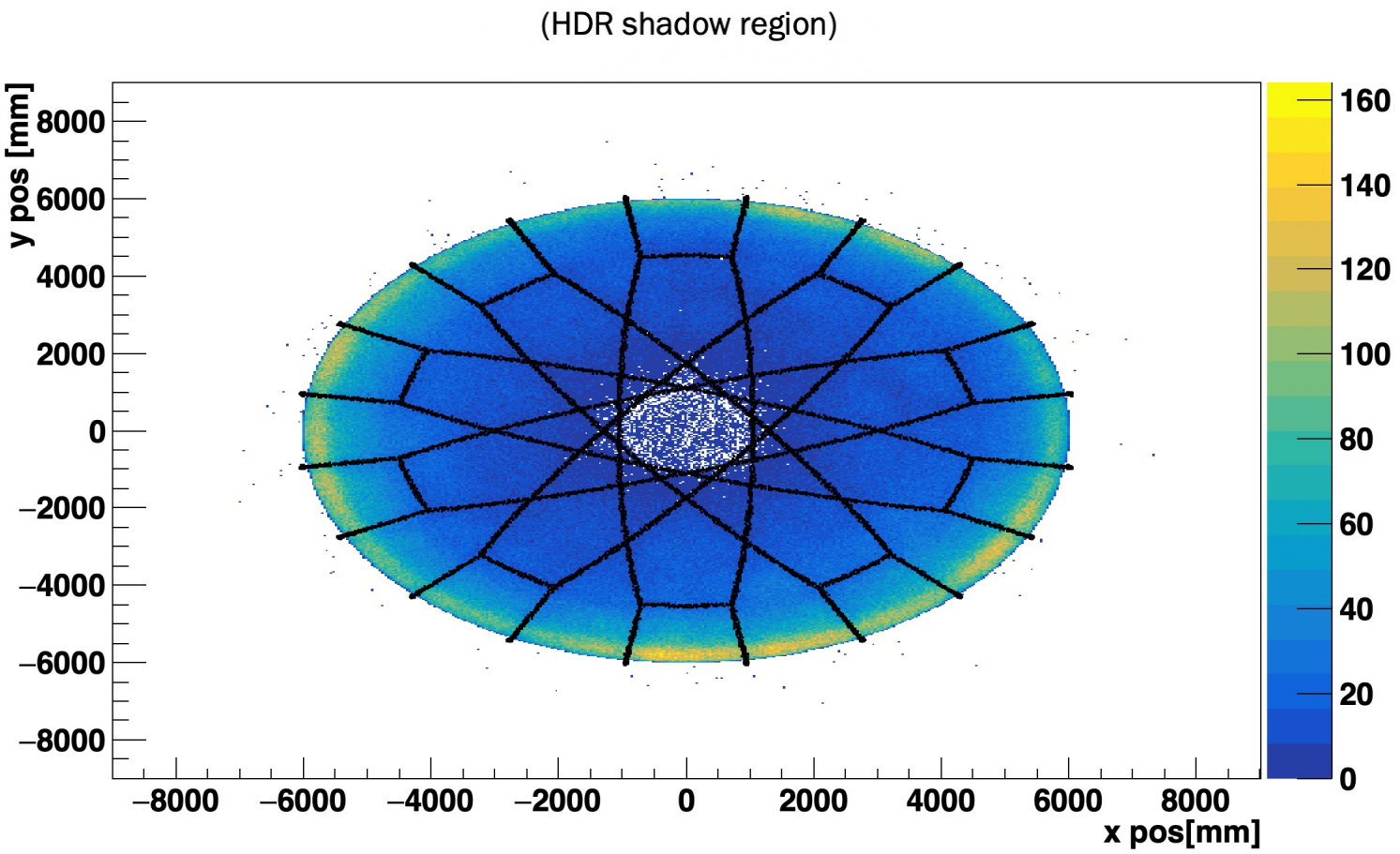

Count
10^4
10^3
10^2
10
1
200
300
400
500
600
700
800
900
1000
1100
# of hit PMTs


Count
10^4
10^3
10^2
10
1
200
300
400
500
600
700
800
900
1000
1100
# of hit PMTs

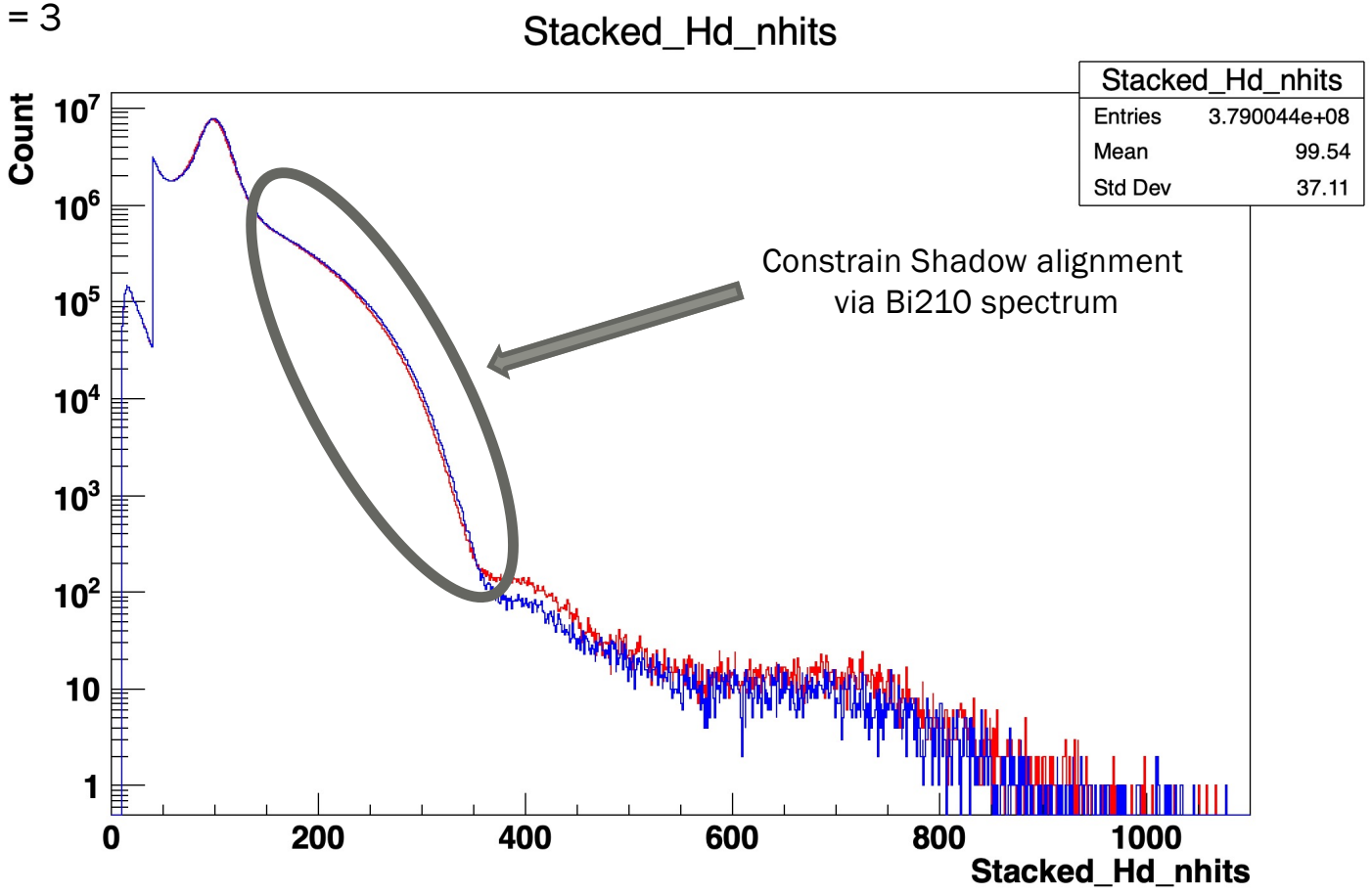

Count
10^4
10^3
10^2
10
1
200
300
400
500
600
700
800
900
1000
1100
# of hit PMTs

SHADOW ALIGNMENT CALCULATION:-


(HDR shadow region)
y pos [mm]
8000
6000
4000
2000
0
−2000
−4000
−6000
−8000
−8000
−6000
−4000
−2000
0
2000
4000
6000
8000
x pos[mm]
160
140
120
100
80
60
40
20
0


(HDR shadow region)
y pos [mm]
8000
6000
4000
2000
0
−2000
−4000
−6000
−8000
−8000
−6000
−4000
−2000
0
2000
4000
6000
8000
x pos[mm]
160
140
120
100
80
60
40
20
0

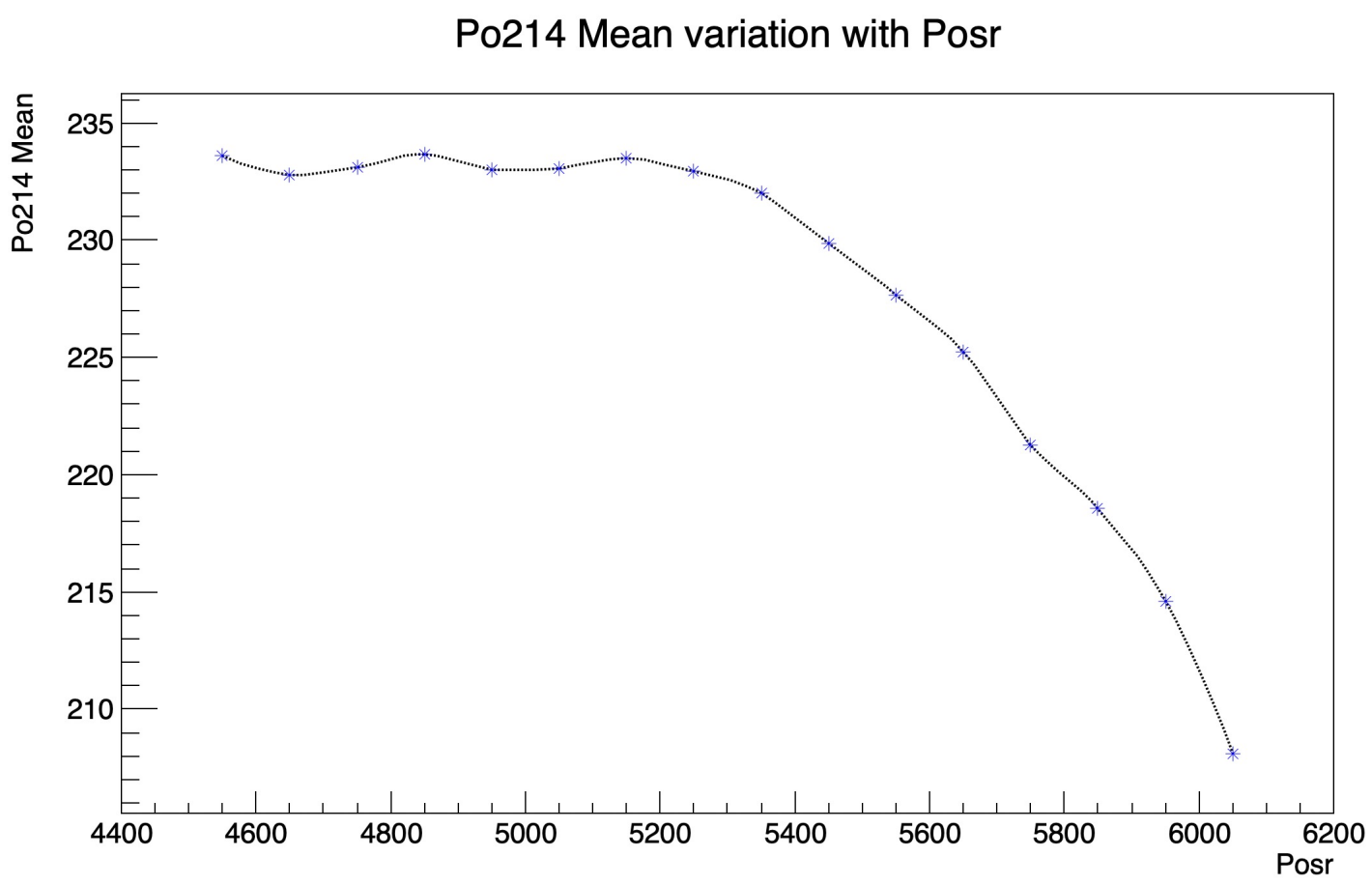
Ang. Width = 3

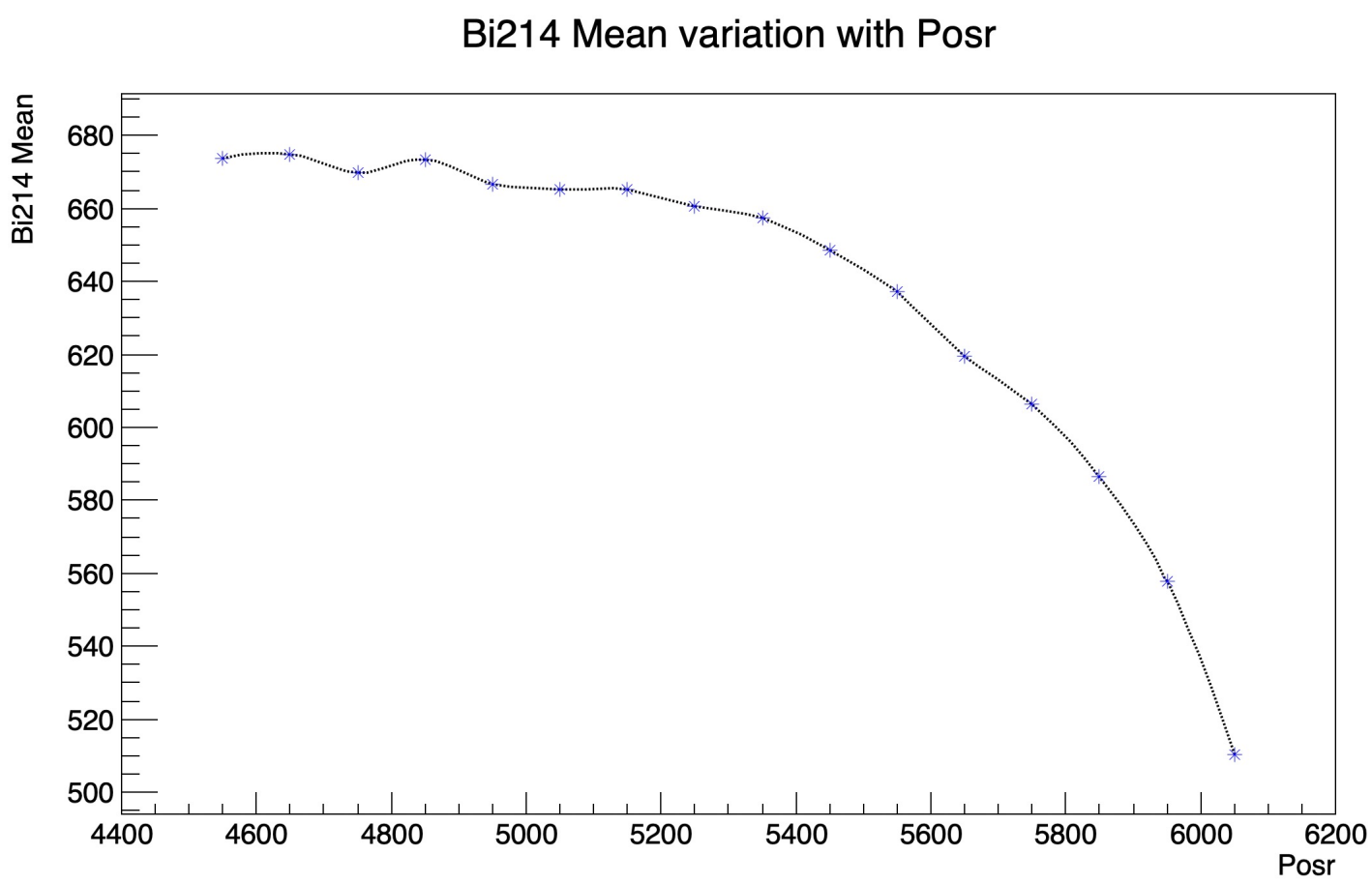

Stacked_Hd_nhits
Stacked_Hd_nhits
Entries 3.790044e+08
Mean 99.54
Std Dev 37.11
Count
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
Stacked_Hd_nhits
Constrain Shadow alignment
via Bi210 spectrum

Optimal cuts:-

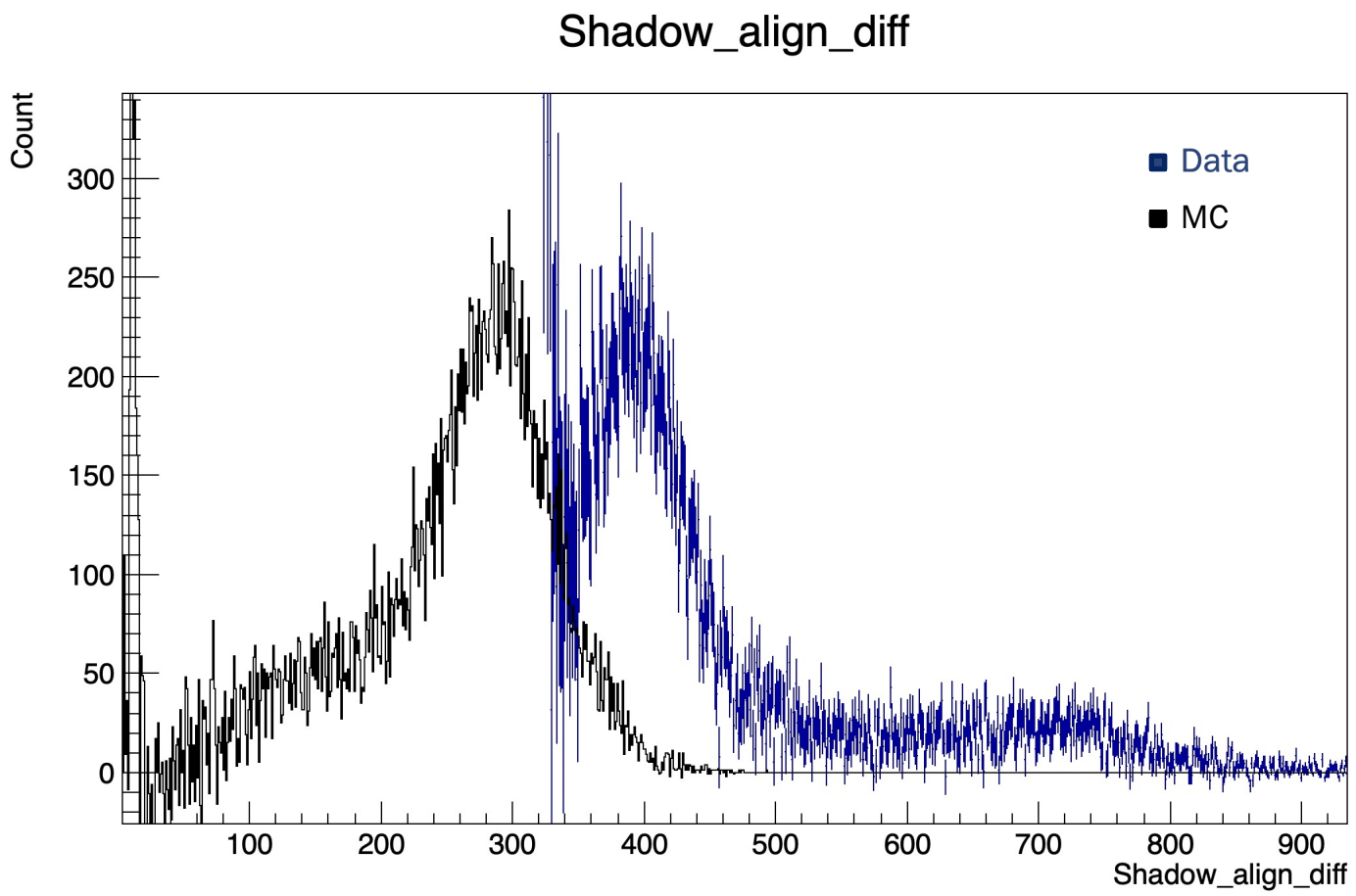
- Azimuthal cut optimized to 3 degrees per section – full spread is at 4.5 degrees
- Provides best compromise between statistics and exclusivity
- Radial cut set to r > 5200 mm for implied consistency with MC where 99% of gammas decay by 800 mm mark from AV wall

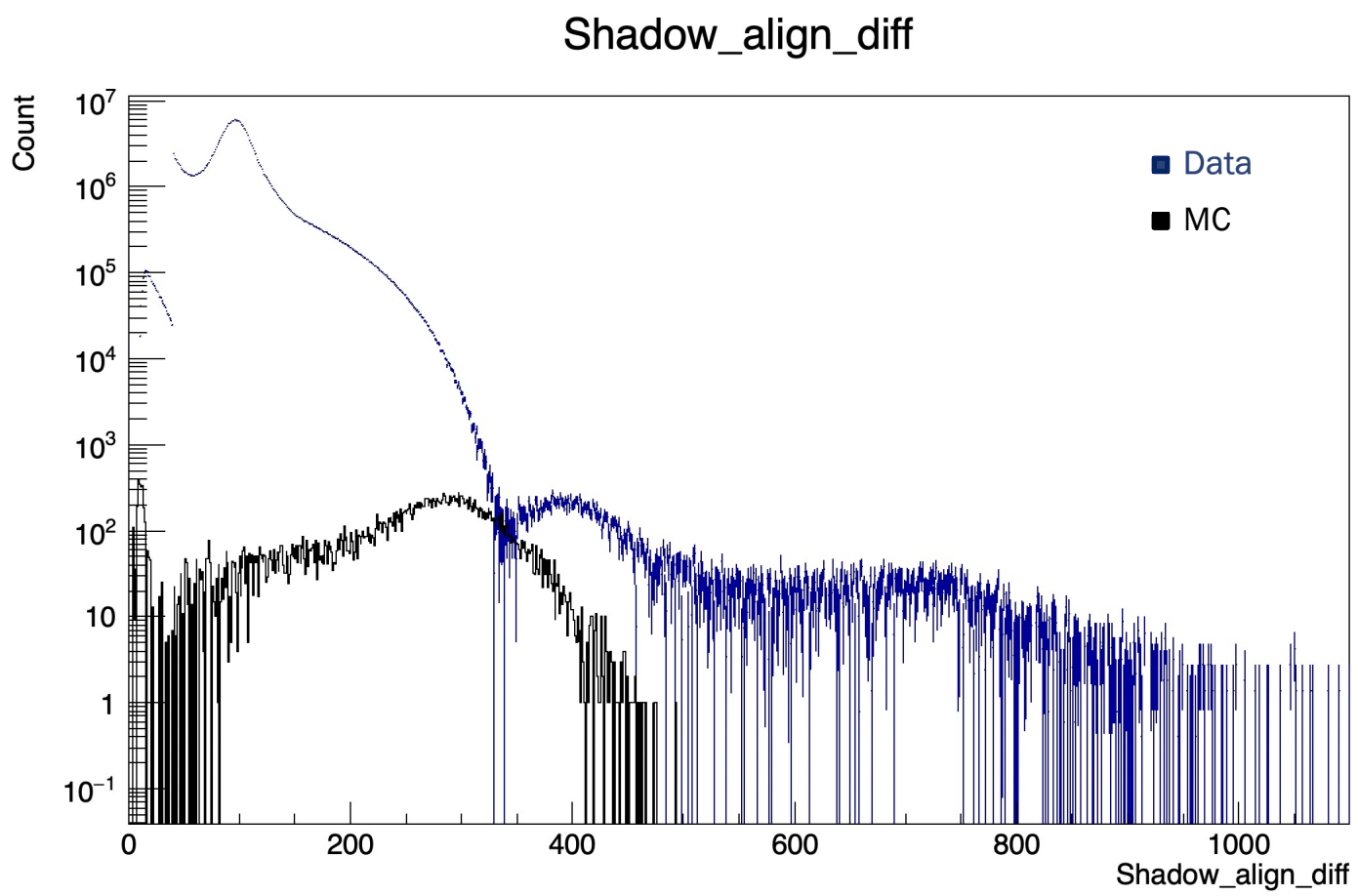
NHIT SHIFT OF BIPO 214:-


Po214 Mean variation with Posr
Po214 Mean
235
230
225
220
215
210
4400
4600
4800
5000
5200
5400
5600
5800
6000
6200
Posr


Bi214 Mean variation with Posr
Bi214 Mean
680
660
640
620
600
580
560
540
520
500
4400
4600
4800
5000
5200
5400
5600
5800
6000
6200
Posr

ALIGNING MC AND DATA:-


Shadow_align_diff
Count
300
250
200
150
100
50
0
100
200
300
400
500
600
700
800
900
Shadow_align_diff
Data
MC


Shadow_align_diff
Count
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
0
200
400
600
800
1000
Shadow_align_diff
Data
MC

$$NErfc\left(\frac{x-\mu-\sigma^2/\lambda}{\sqrt{2}\sigma}\right)\times\exp\left(\frac{x-\mu-\sigma^2/\lambda}{\lambda}\right)$$

MC:-

1	p0	6.48834e+01
2	p1	2.71133e+02
3	p2	3.91655e+01
4	p3	3.59189e+01

Data:-

1	p0	1.59513e+00
2	p1	7.70196e+01
3	p2	4.51775e+01
4	p3	1.26240e+01