Charge Identification in Nuclear Emulsions (2019 GSI Data Taking)

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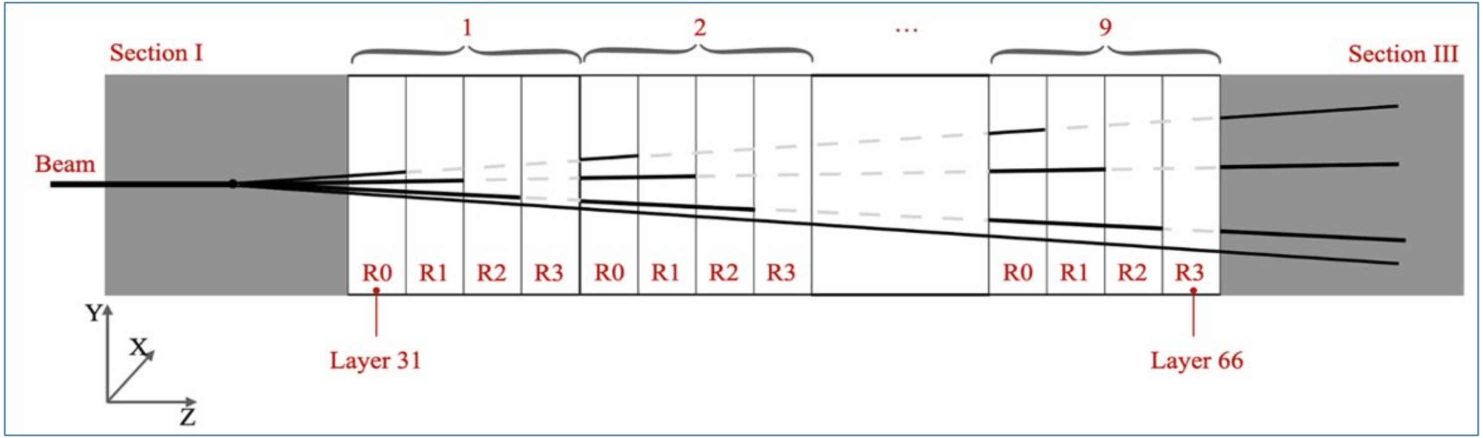
Outline

- Structure of Section 2 (S2) of the Emulsion Spectrometer for charge identification;
- Charge Identification for GSI3 data;
- Comparisons with MC (true and reconstructed) simulations;

BEAM / TARGET	^{16}O 200 MeV/n	^{16}O 400 MeV/n
Carbon	GSI1	GSI3
Polyethylene	GSI2	GSI4

Charge Identification in Section 2 (S2): Refreshing

- Section 2 is divided into nine cells, each consisting of four emulsion films (Nagoya emulsions), which undergo different thermal treatments that partially (or totally) erase the base-tracks;

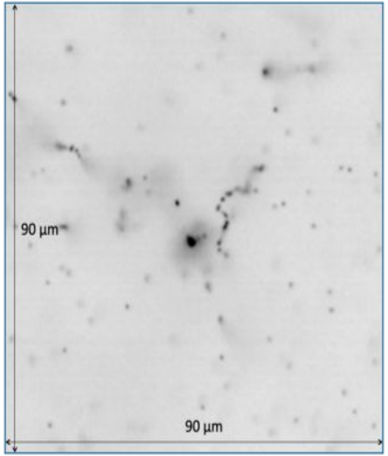


Ref: "Charge Identification of fragments with the emulsion spectrometer of the FOOT experiment"

R0: Not thermally treated	**R2**: 24 h at T2 = 34°C and RH = 95%
R1: 24 h at T1 = 28°C and RH = 95%	**R3**: 24 h at T3 = 36°C and RH = 95%

Charge Identification in Section 2 (S2): Variables

- In order to identify the charge of the incoming particles, the following variables are employed:
  - tan(ϑ) ⟶ the tangent of the inclination of the most upstream fitted track segment w.r.t. the Z axis;
  - k_x ⟶ the number of base-tracks belonging to a given track for each set of thermal treatments Rx (x = 0, 1, 2, 3);
  - VRX ⟶ the "volume" of the base-tracks, defined as the sum of the number of pixels (each weighted for its brightness) corresponding to the sensitized grains in the digital image;
  - $VRX_{av} = \Sigma_{kx} VRX / k_x$



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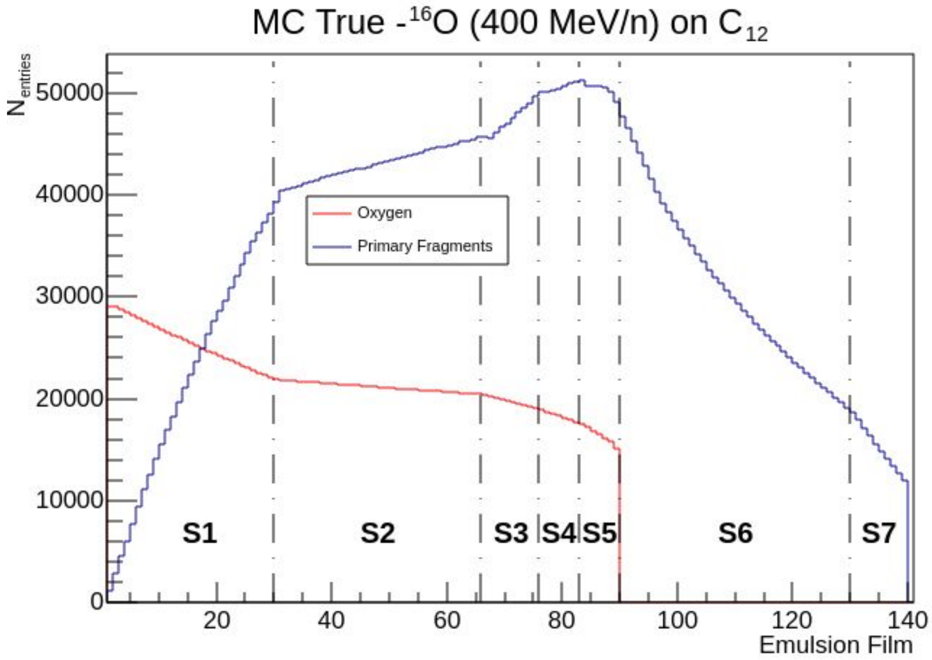
    - $VRX_{av} = \Sigma_{kx} VRX / k_x$

→ Particle's charge is identified either by **sharp cuts** on the average volume variables and tan(ϑ) or by combining the average volume variables with the **Principal Component Analysis (PCA)**

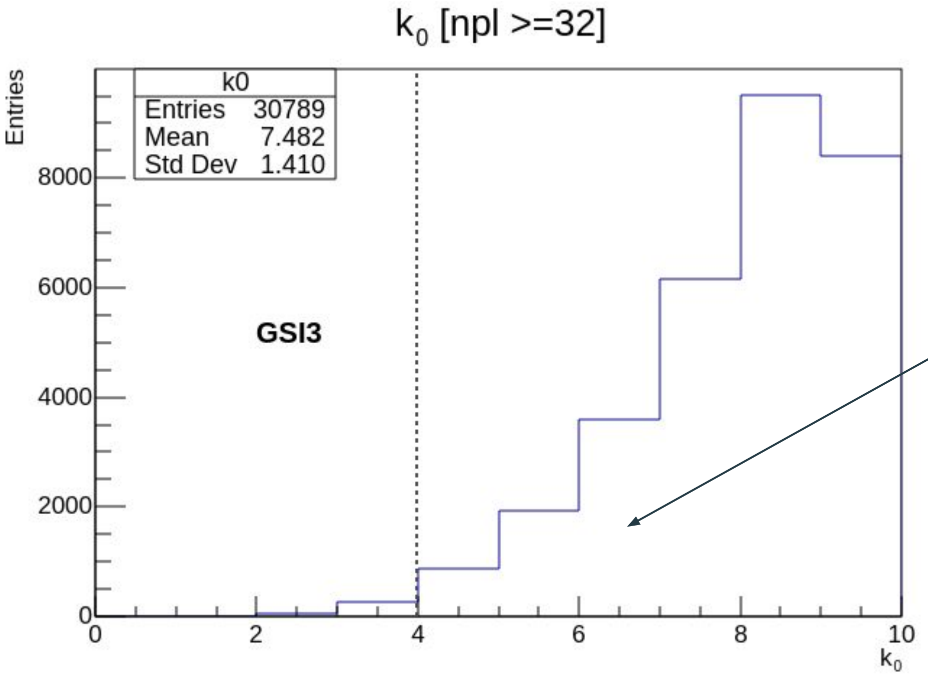
Charge ID for GSI3: Position of the Bragg Peak

- GSI3 refers to the exposure of a graphite target with a 400 MeV/n ^{16}O beam;
- The Bragg Peak of the primaries occurs after Section 2;



Charge ID for GSI3: Tracking Efficiency Estimate

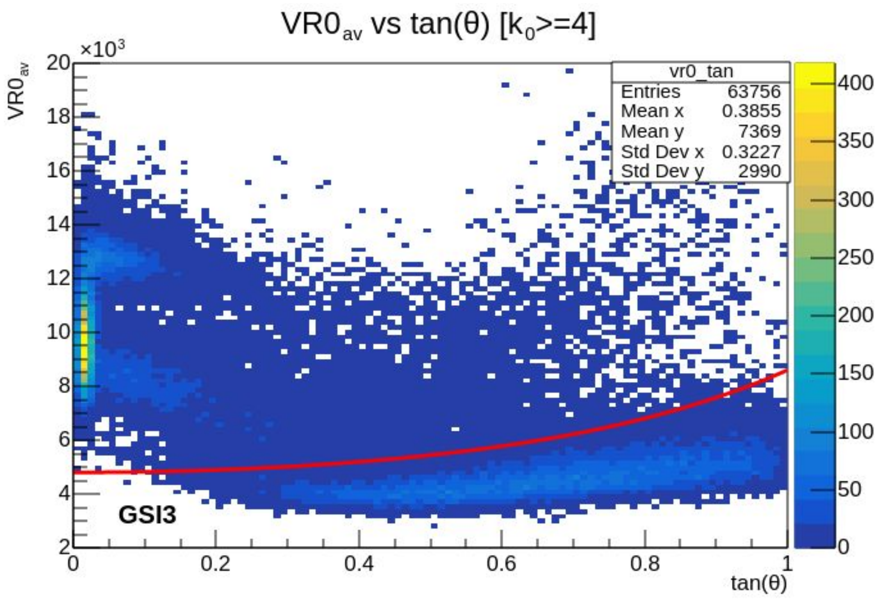
- Tracking efficiency has been estimated by using long tracks that cross 9 R0 regions;
- Fragments stopping in S2 with less than 4 segments = about 3-4% (from MC true);

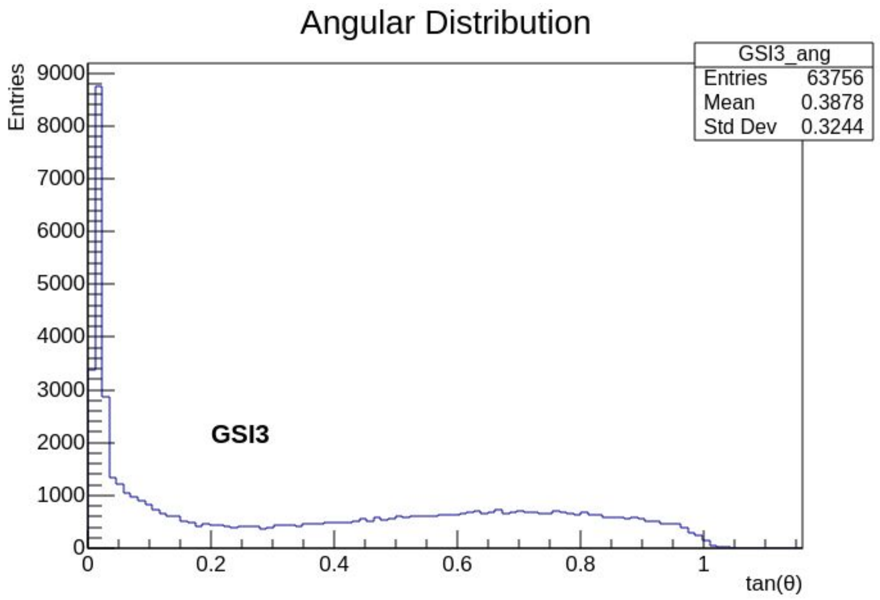


Cut on k_0>=4

GSI3: Identification of Cosmic Rays

- Cut k_0>=4 for all plots;
- The highly populated bins at low angles are due to the presence of primary beam in S2;

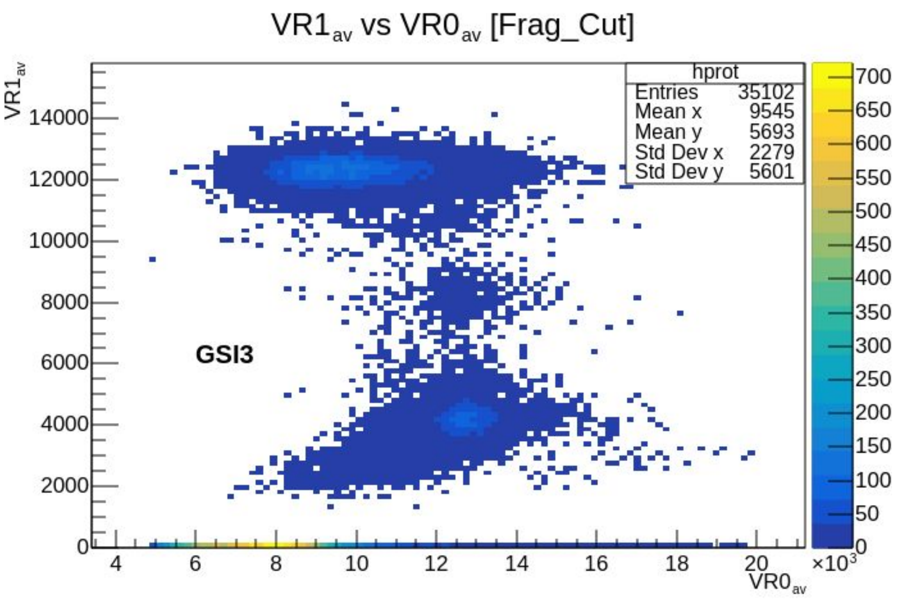


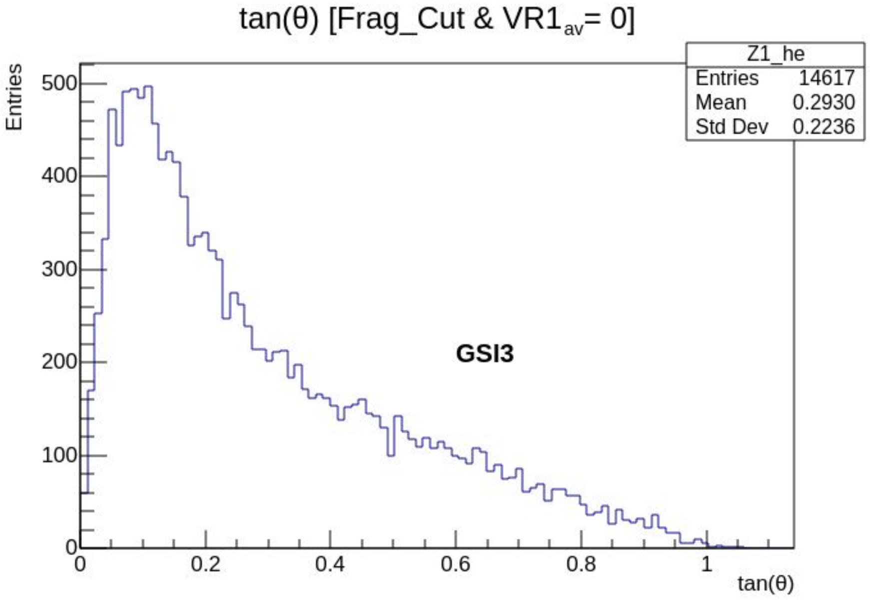


"Frag Cut": $VR0_{av} \geq a_2 \cdot \left(1 + e^{b_2 \cdot \tan^2(\vartheta)}\right),\ a_2 = 2400,\ b_2 = 0.95$

GSI3: Identification of Z = 1 Fragments

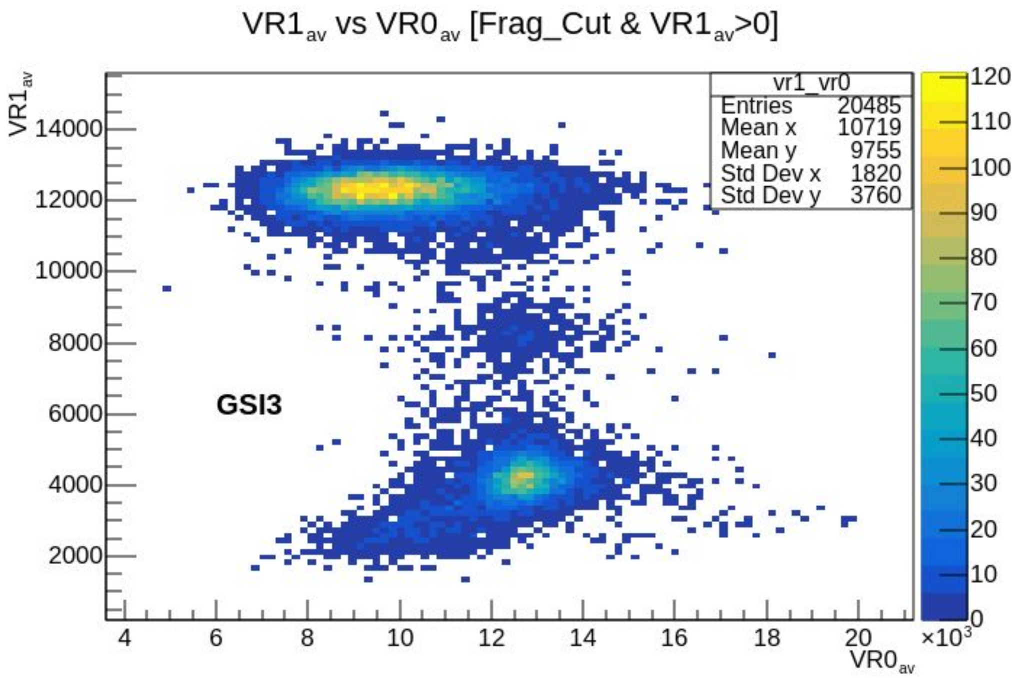
- Tracks that do not survive R1 thermal treatment have the lowest ionization and are thus identified as Z = 1 fragments;





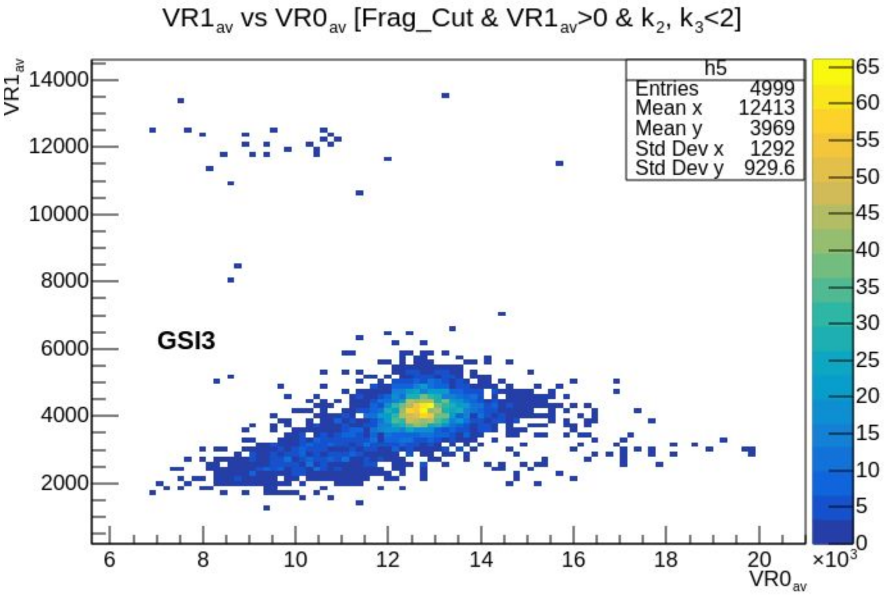
GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (1)

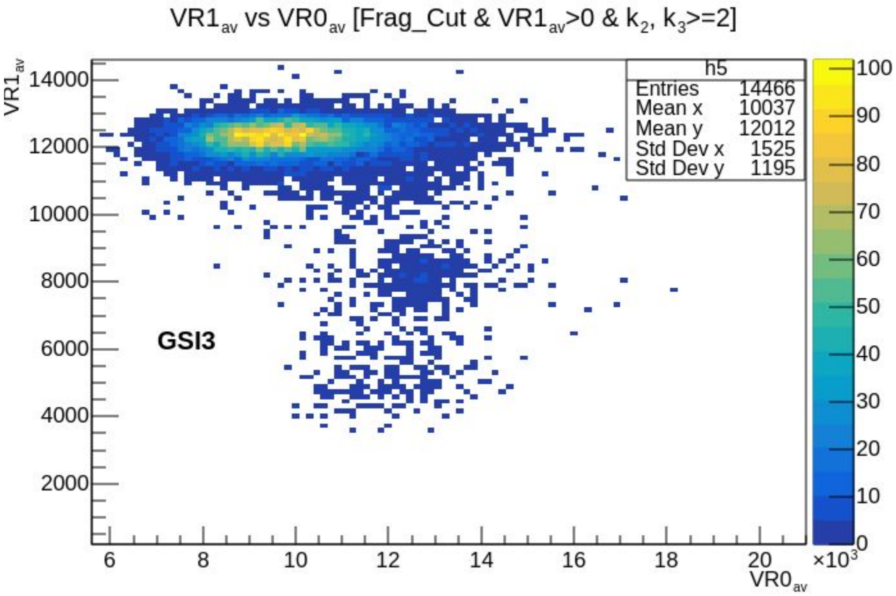
- $VR1_{av}$ and $VR0_{av}$ variables show the presence of at least two distinct populations;



GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (2)

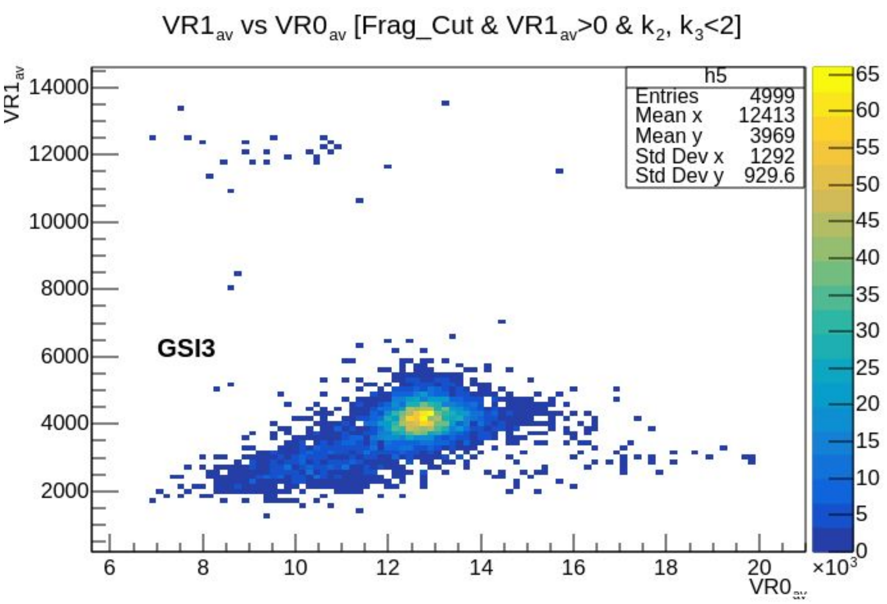
- Most of the tracks in the lower population do not have a significant amount of segments in the R2 and R3 regions;

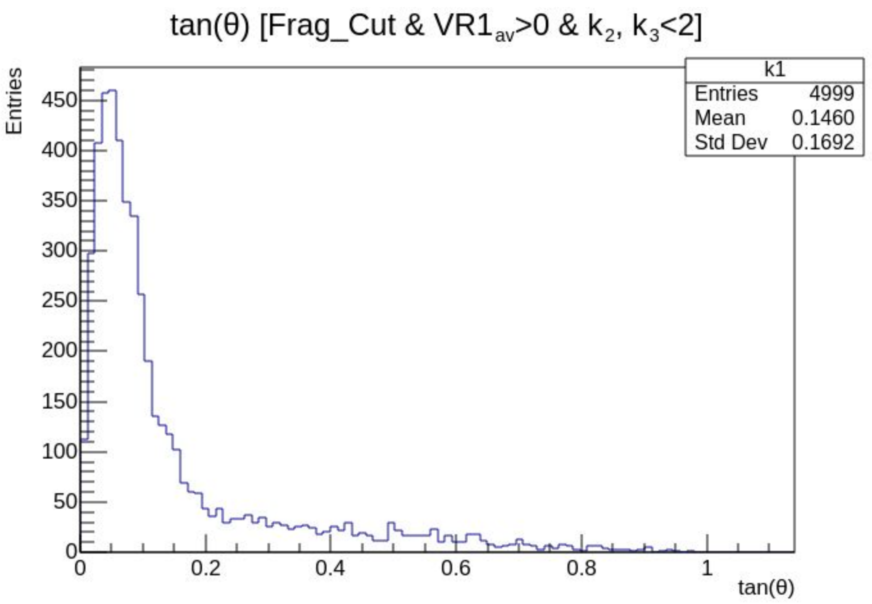




GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (2)

- Tracks belonging to the lower population also have a narrower angular distribution w.r.t. to Z=1 fragments;

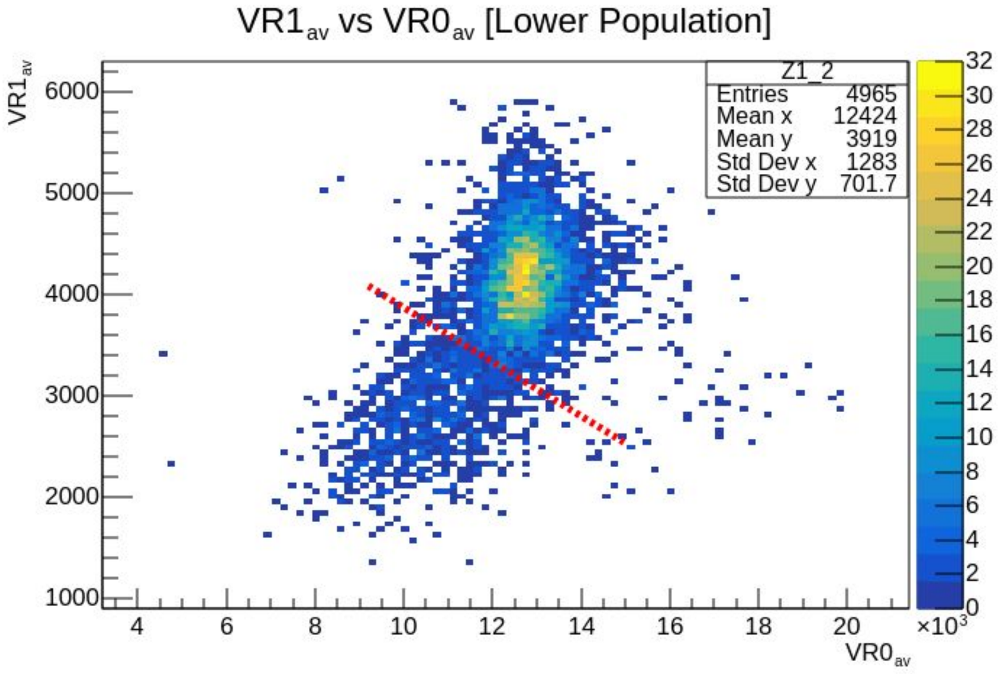




→ ***Z = 2?***

GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (3)

- A more accurate analysis shows that there are actually two populations with different average volume variables and angular distributions;



GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (4)

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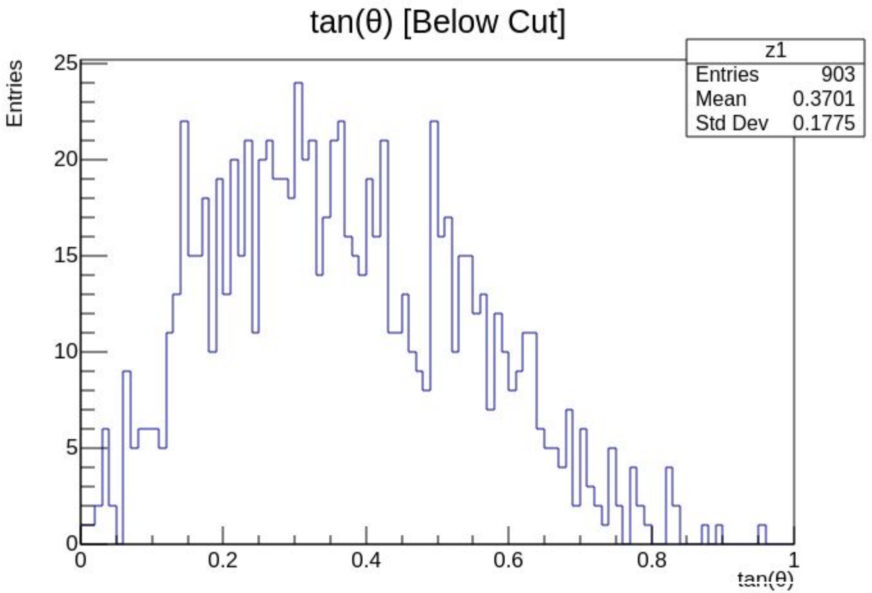
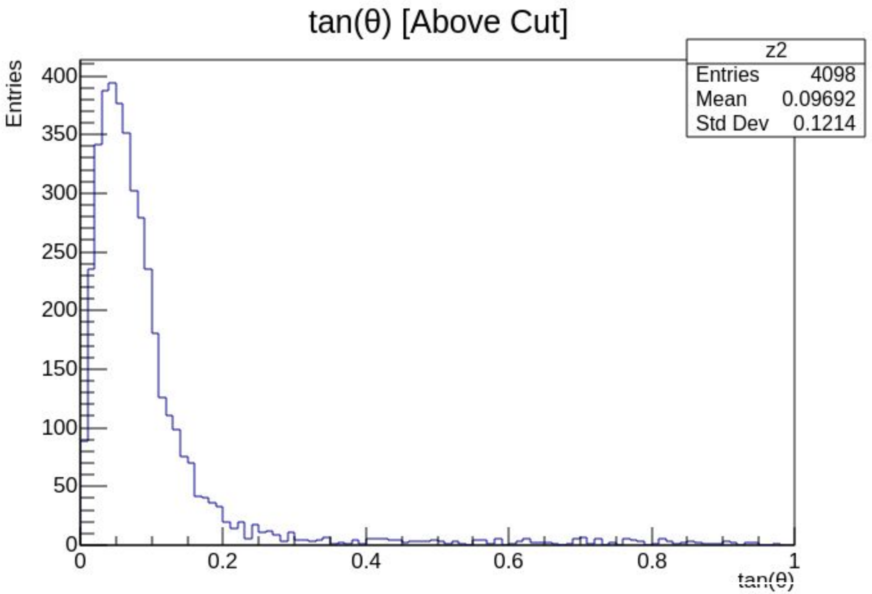


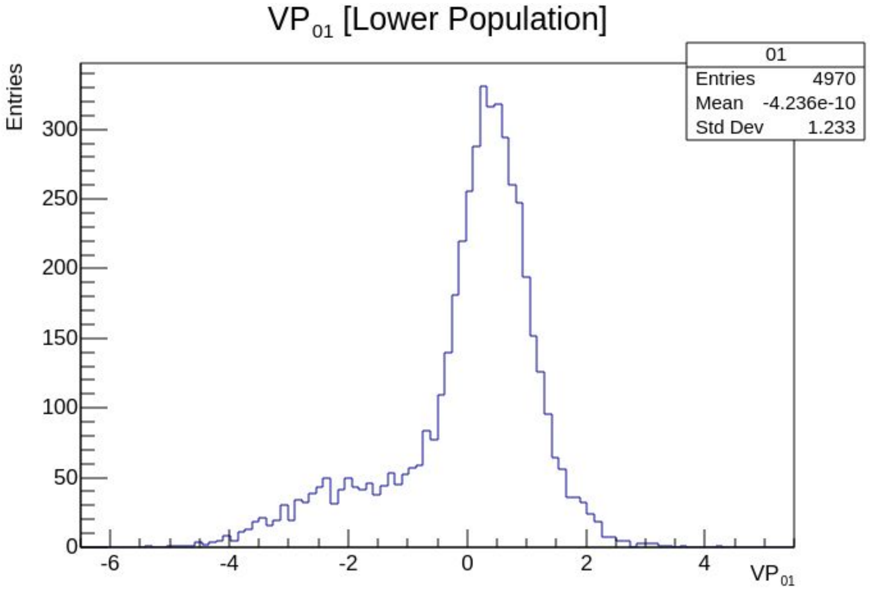
Z = 1 (Low Energy)

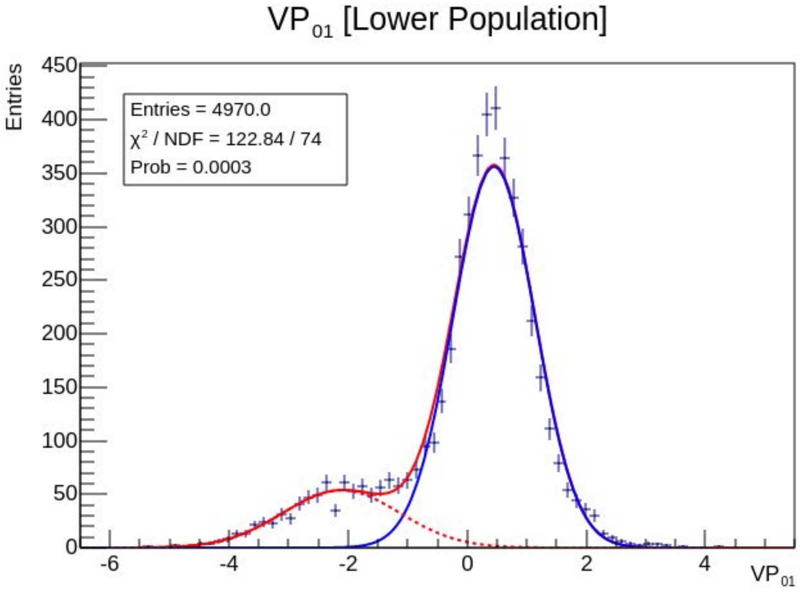


Z = 2

GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (5)

- A better classification can be achieved by combining $VR0_{av}$ and $VR1_{av}$ variables with the PCA, thus avoiding the use of a sharp cut;





GSI3: $VR1_{av}$ vs $VR0_{av}$ distribution (6)

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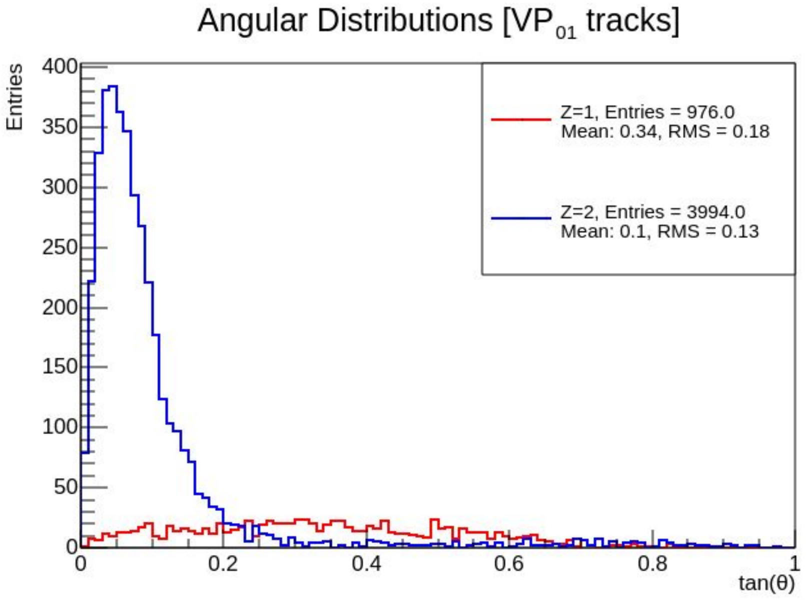
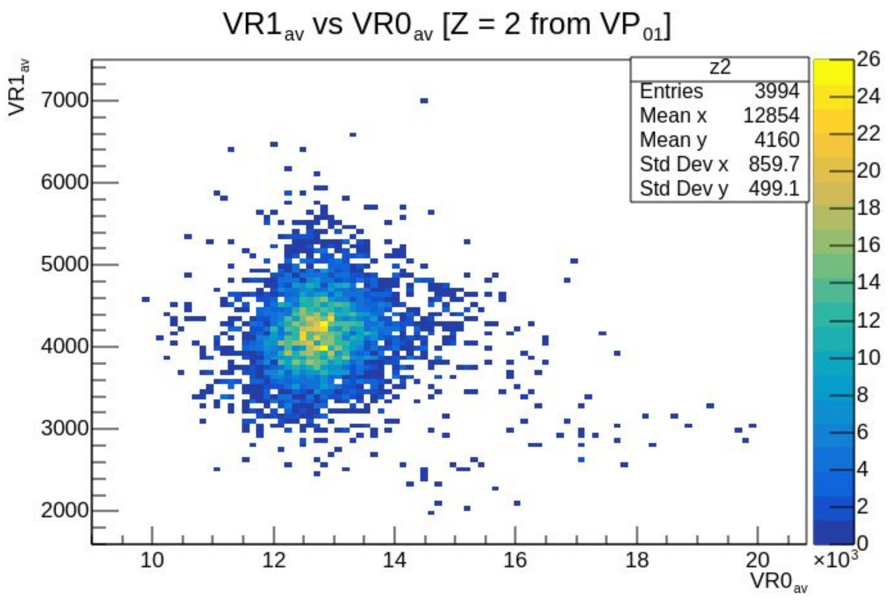
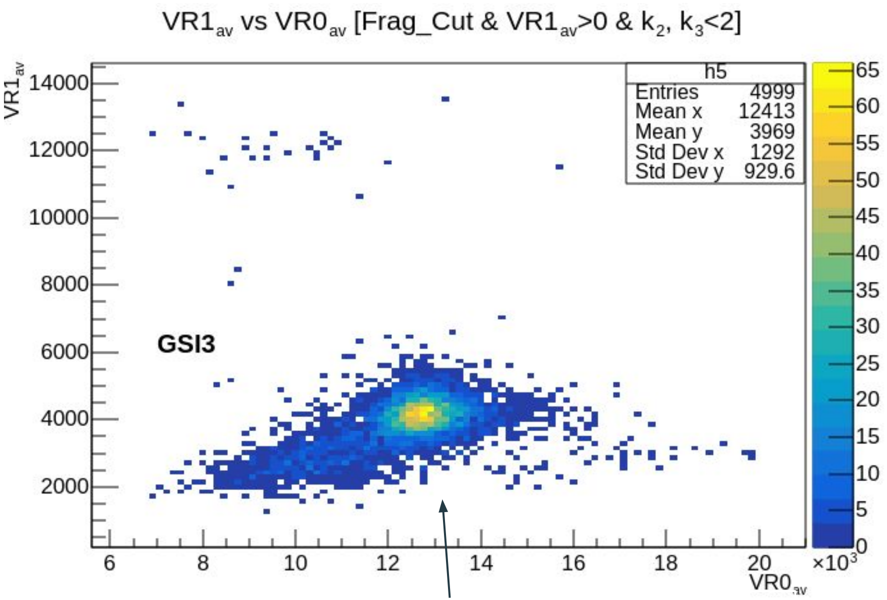


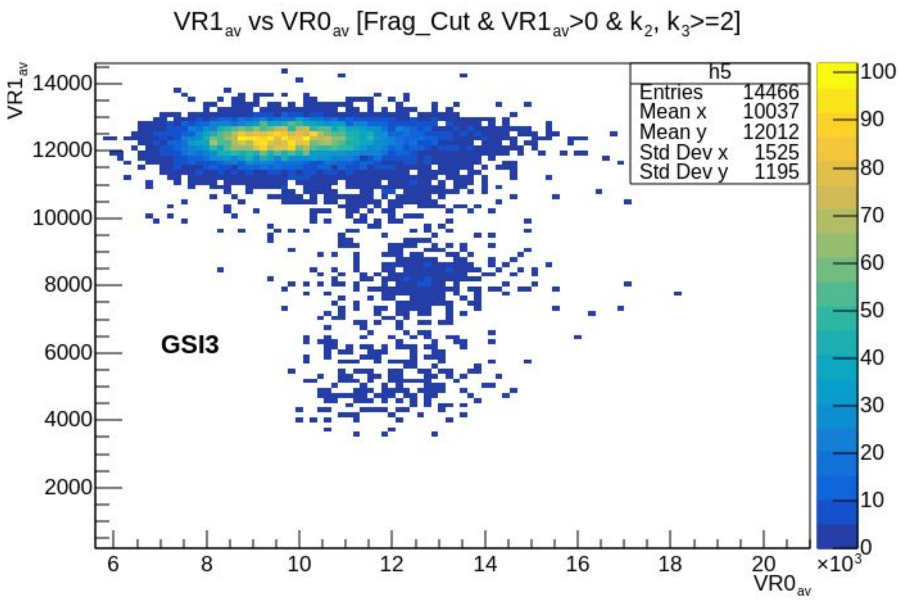


GSI3: Identification of Z>=2 Fragments

- Still need to classify the tracks that have at least 2 segments either in the R2 or R3 regions;

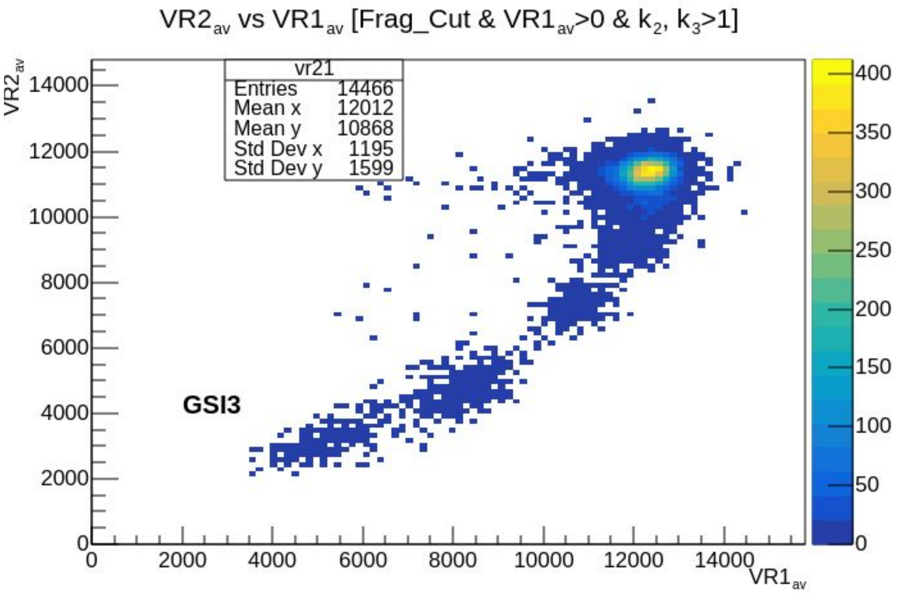


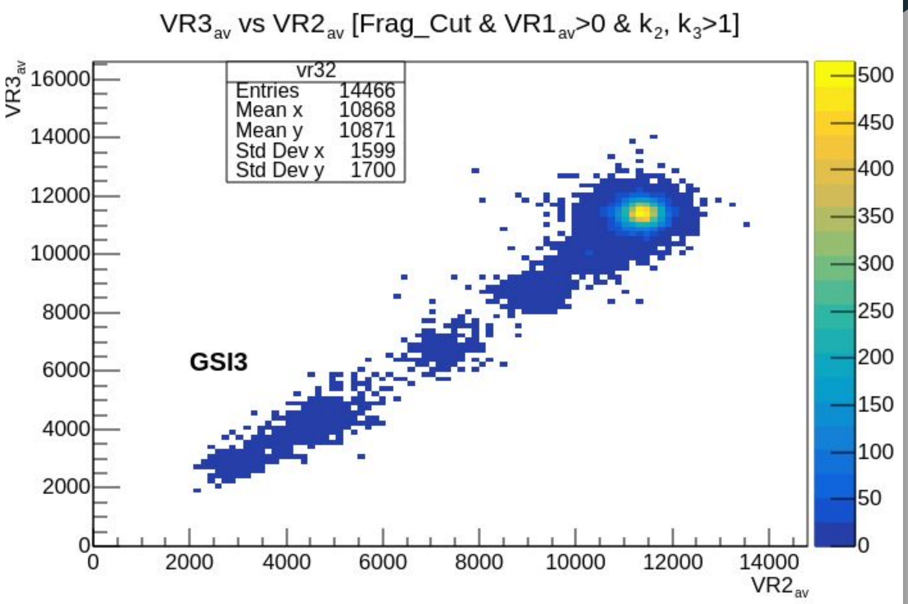
Classified as Z=1 or Z=2



GSI3: Identification of Z>=2 Fragments

- Still need to classify the tracks that have at least 2 segments either in the R2 or R3 regions;
- For these tracks it is useful to study the average volume variables in the regions following R1;





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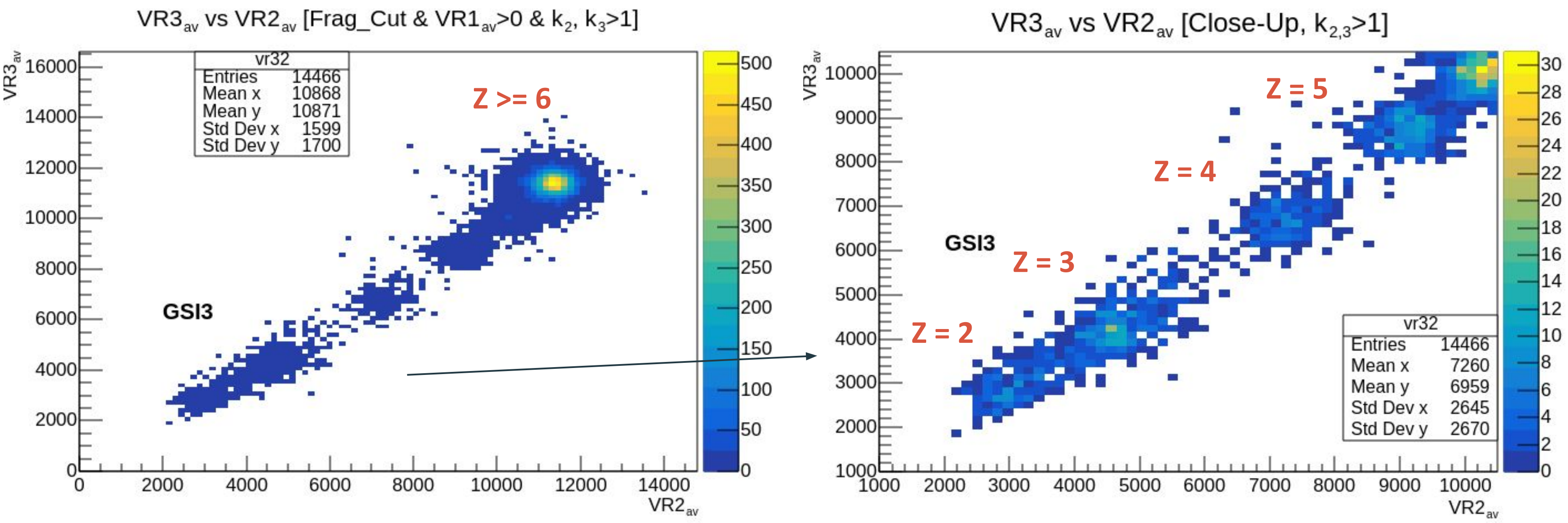
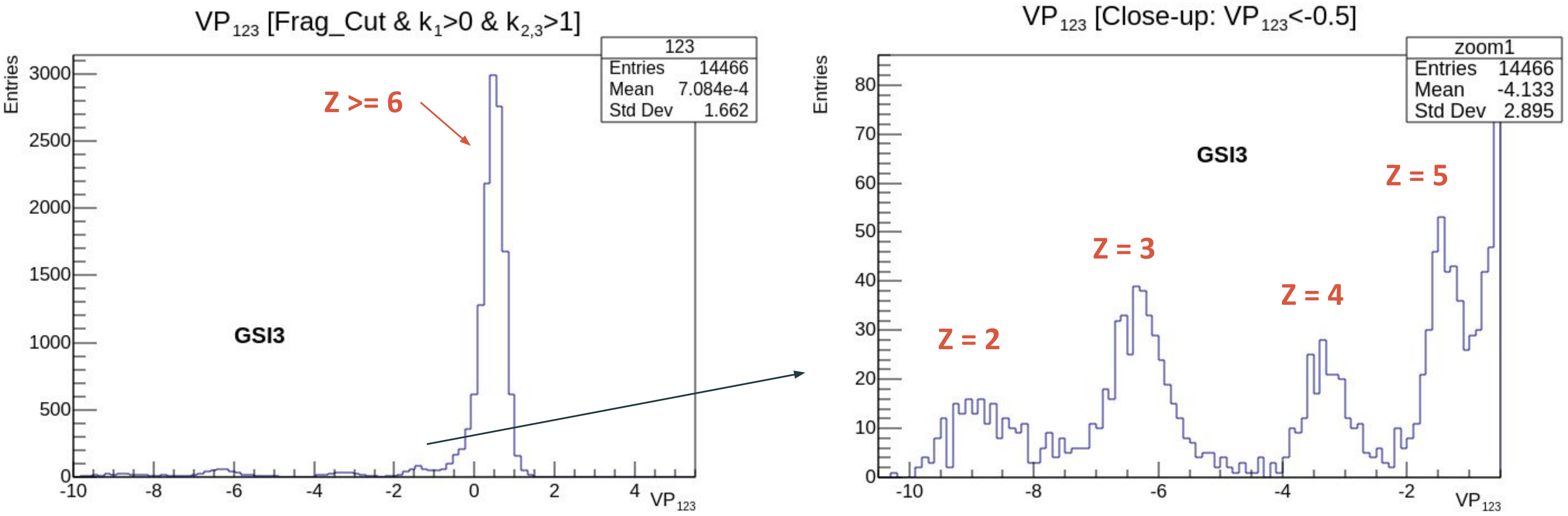


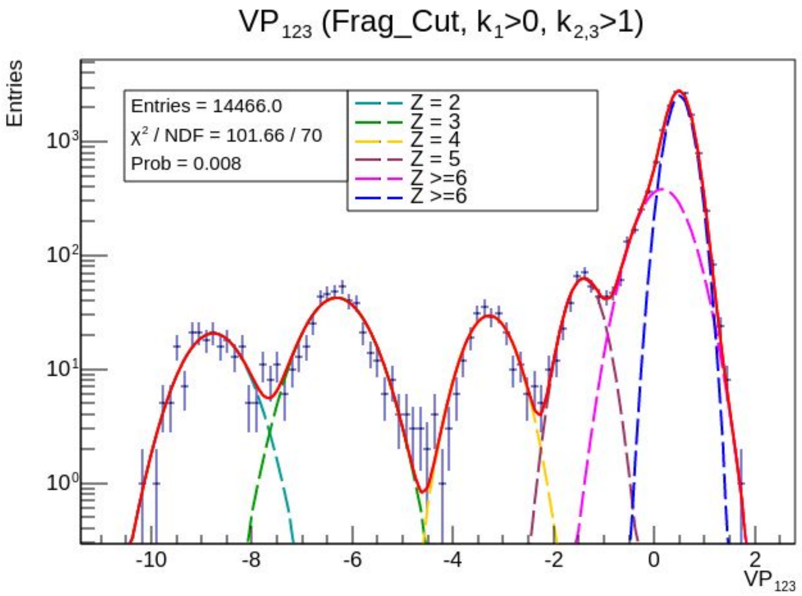
GSI3: Identification of Z>=2 Fragments

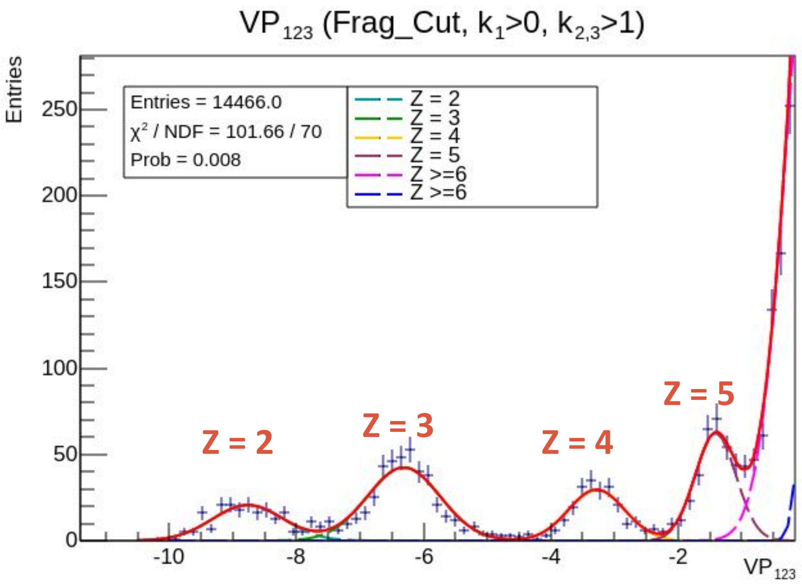
- The combination of $VR1_{av}$, $VR2_{av}$ and $VR3_{av}$ variables via the PCA (**VP_{123}**) highlights the different populations more clearly;



GSI3: Identification of Z>=2 Fragments

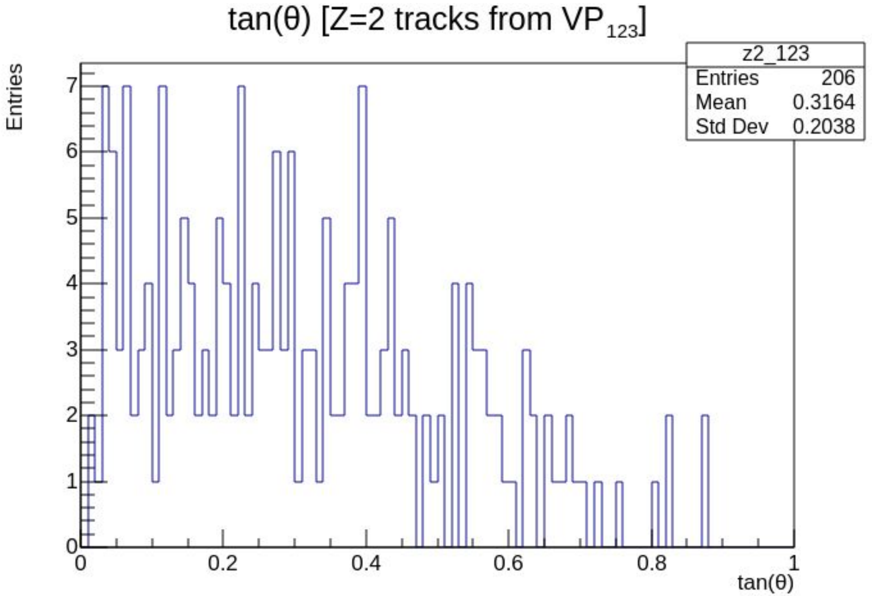
- A fit with a sum of 6 Gaussians has been performed on the **VP$_{123}$** distribution;

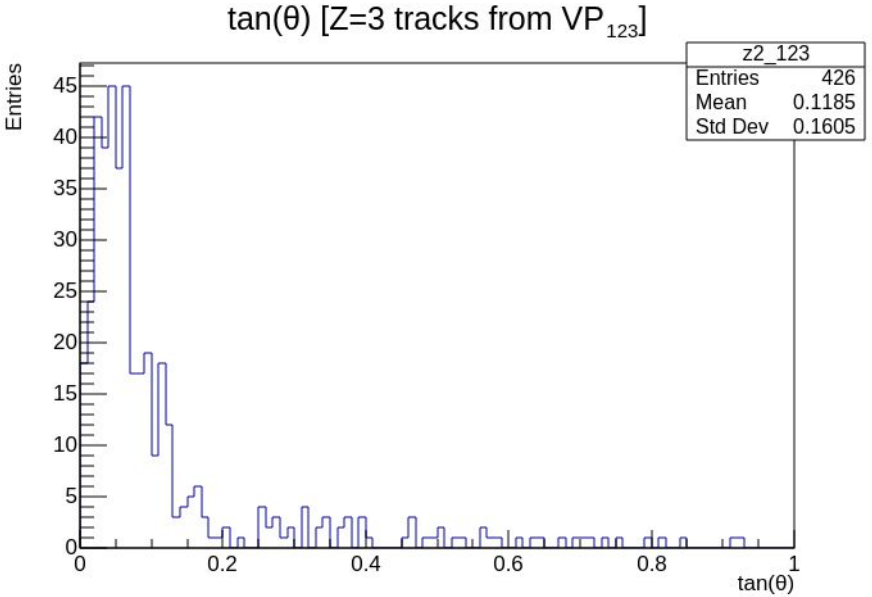




GSI3: Identification of Z>=2 Fragments

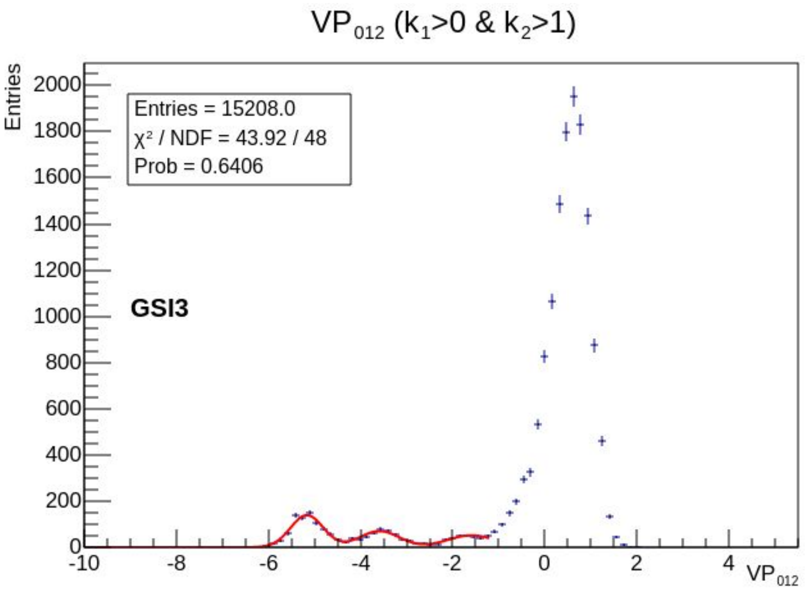
- The angular distribution of tracks belonging to the first peak points to their classification as a lower energy tail of Z=2 fragments;

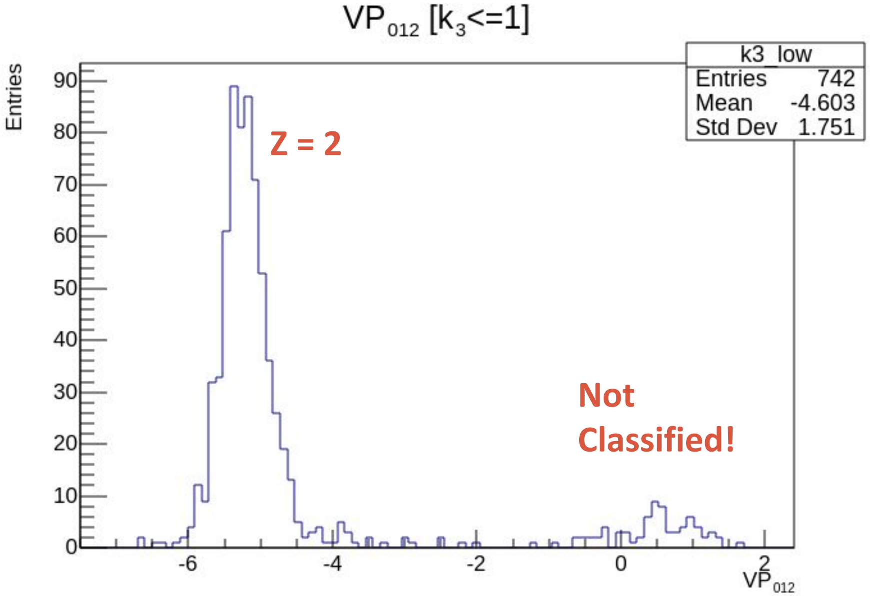




GSI3: Identification of Z>=2 Fragments

- Tracks that satisfied the cut $k_1>0$, $k_2>1$ and $k_3<=1$ were classified in a similar manner by using the **VP_{012}** variable;





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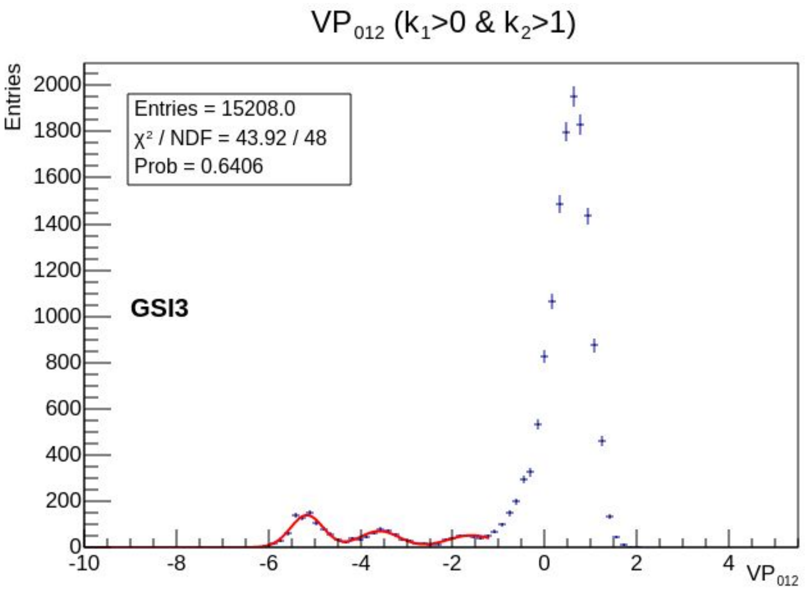
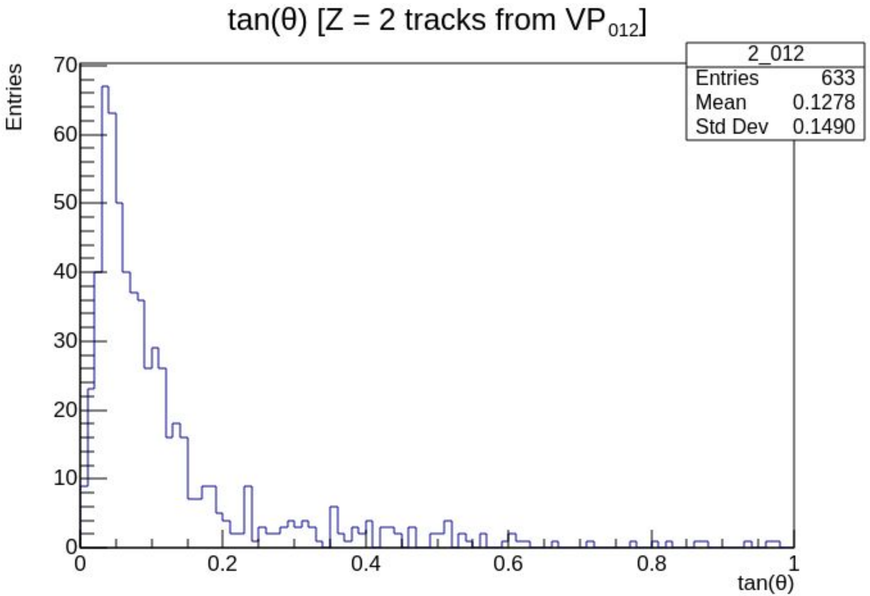
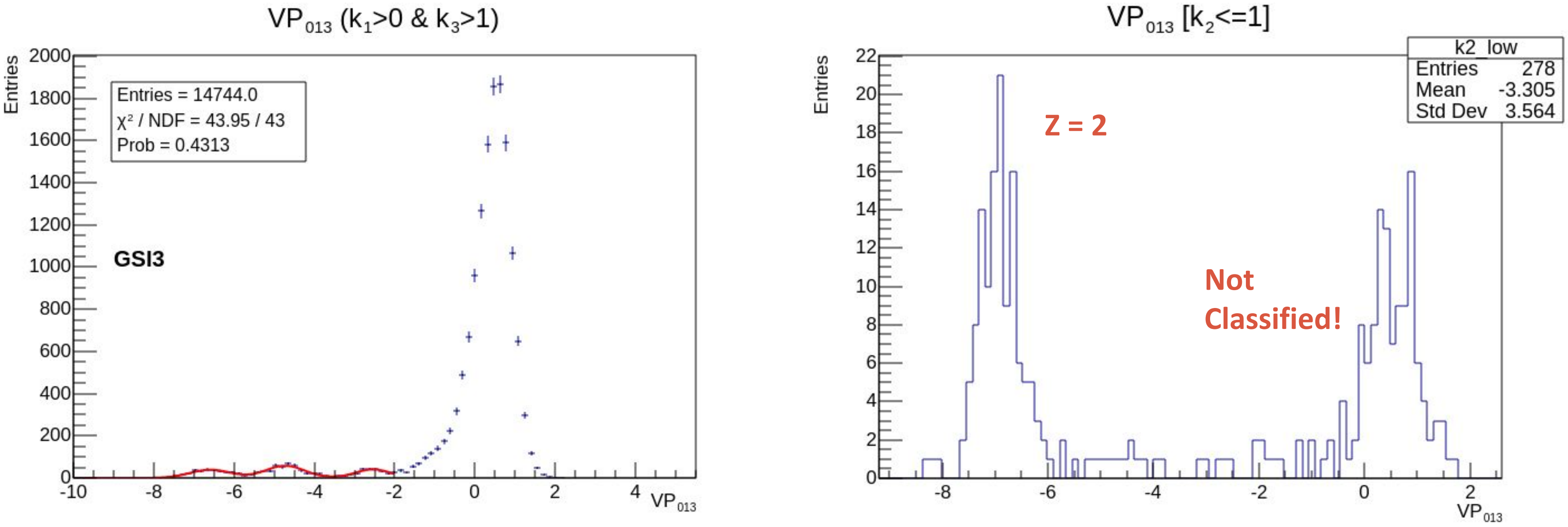
- Tracks that satisfied the cut $k_1>0$, $k_2>1$ and $k_3<=1$ were classified in a similar manner by using the $\mathbf{VP_{012}}$ variable;





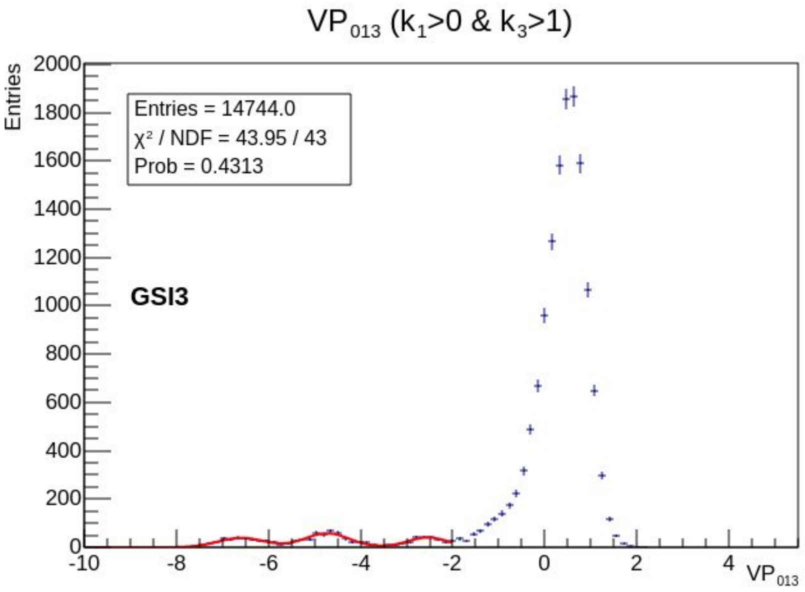
GSI3: Identification of Z>=2 Fragments

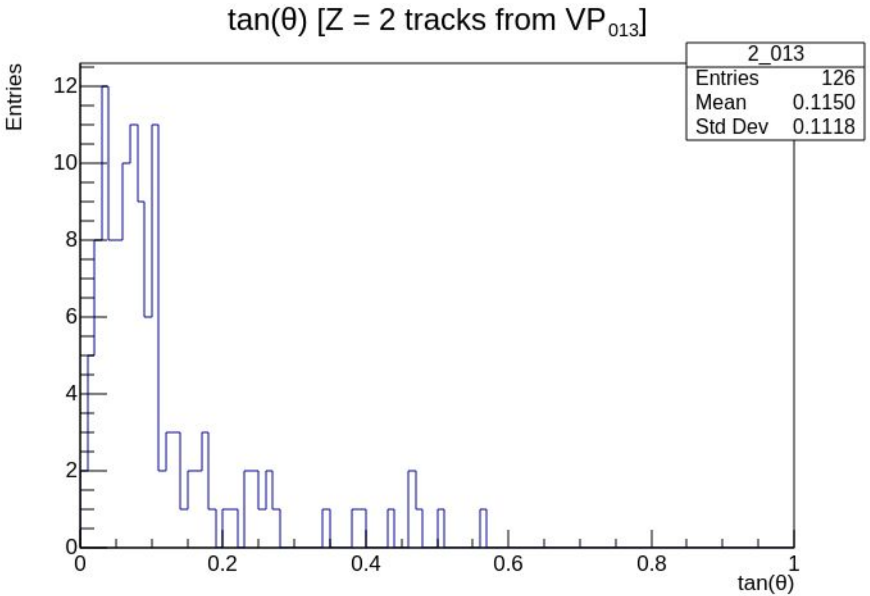
- Tracks that satisfied the cut $k_1>0$, $k_2<=1$ and $k_3>1$ were classified in a similar manner by using the $\mathbf{VP_{013}}$ variable;



GSI3: Identification of Z>=2 Fragments

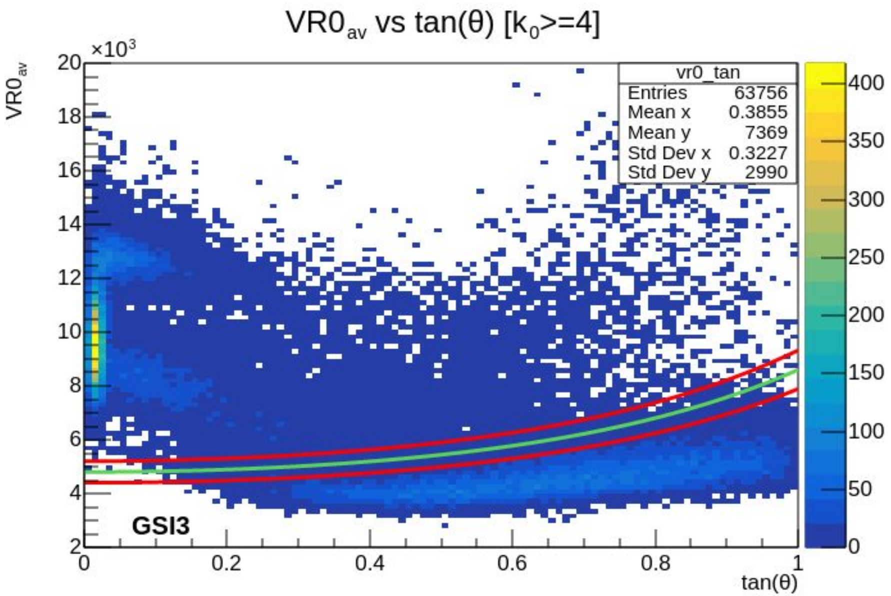
- Tracks that satisfied the cut $k_1>0$, $k_2<=1$ and $k_3>1$ were classified in a similar manner by using the **VP_{013}** variable;





GSI3: Sharp Cut Error Estimate

- Errors in charge identification arise from the choice of the sharp cut and from the uncertainties in the fits of the VPs variables;



Z	cut1	cut2	cut3
Cosmic Rays	27062 (42.4%)	28654 (44.9%)	29802 (46.7%)
1 (H.E.)	16209 (25.4%)	14617 (22.9%)	13470 (21.1%)

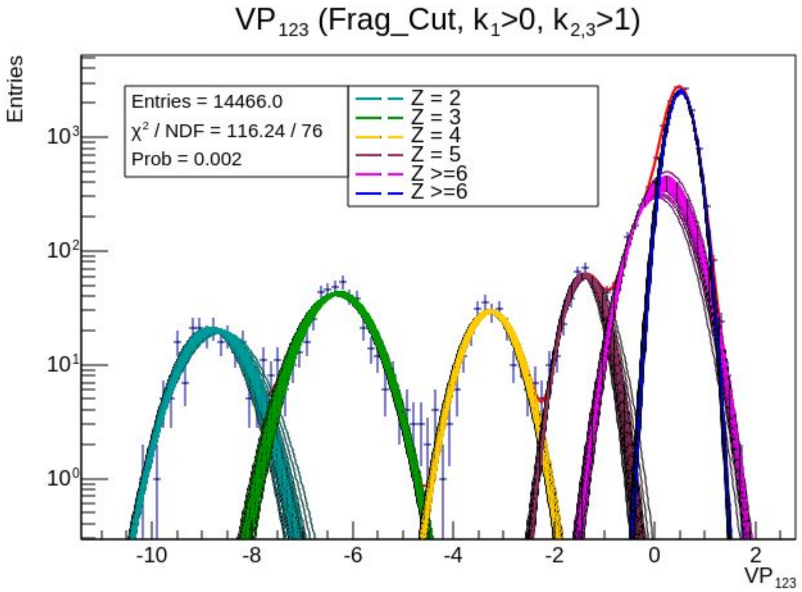
Tracks with $VR1_{av} = 0$

ERROR = (Max - Min) / 2 = 1370 trks

Note: The sharp cut on $VR0_{av}$ and tan(ϑ) <u>does not</u> significantly change the number of tracks with $VR1_{av}>0$ included in the classification

GSI3: PCA Error Evaluation

- Two components: systematic error of the chosen fit and errors of fit parameters;
- Systematic component evaluated by repeating the fits with 3 different binnings, errors of the fit parameters evaluated by repeating the fits N=100 times and fixing the means of the gaussians;



Z	#trks	σ	σ/#trks
2	203	5	2.4%
3	429	5	1.2%
4	229	1	0.5%
5	361	13	3.6%
>=6	13245	12	0.1%

GSI3: Comparison between data and MC

- Expected fractions of the different atomic species as predicted by the analysis carried out on the data and MC simulations (both true and reconstructed);

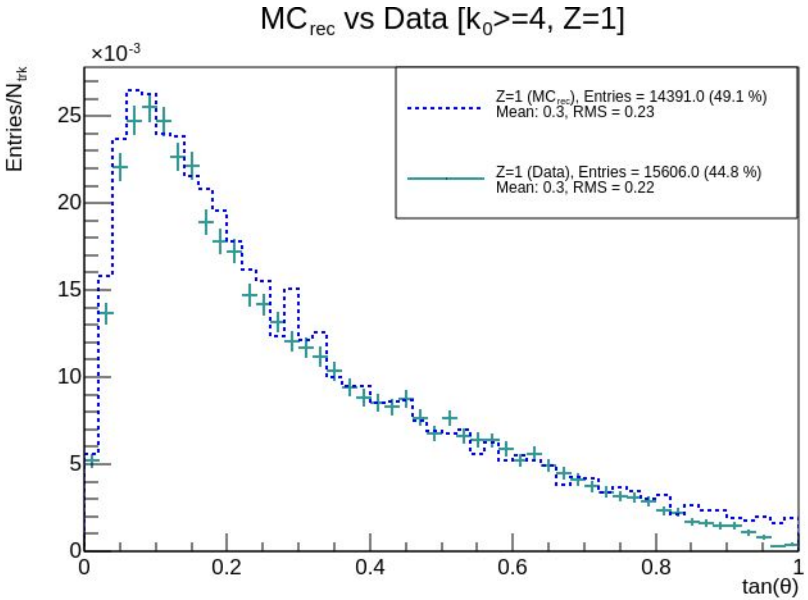
Z	MC TRUE (nsegS2>=4)	MC RECO (nsegS2>=4)	DATA (syst. err. ± stat. err.)
1	46.0 %	49.4 %	44% ± 3.9% ± 0.4%
2	10.8 %	13.4 %	14.5% ± 0.1% ± 0.2%
3	0.9%	1.1 %	1.2% ± 0.00% ± 0.06%
4	0.4 %	0.5 %	0.6% ± 0.00% ± 0.04%
5	0.5 %	0.6 %	1.0% ± 0.00% ± 0.05%
>=6	41.3 %	35.0%	38.0% ± 0.00% ± 0.3%

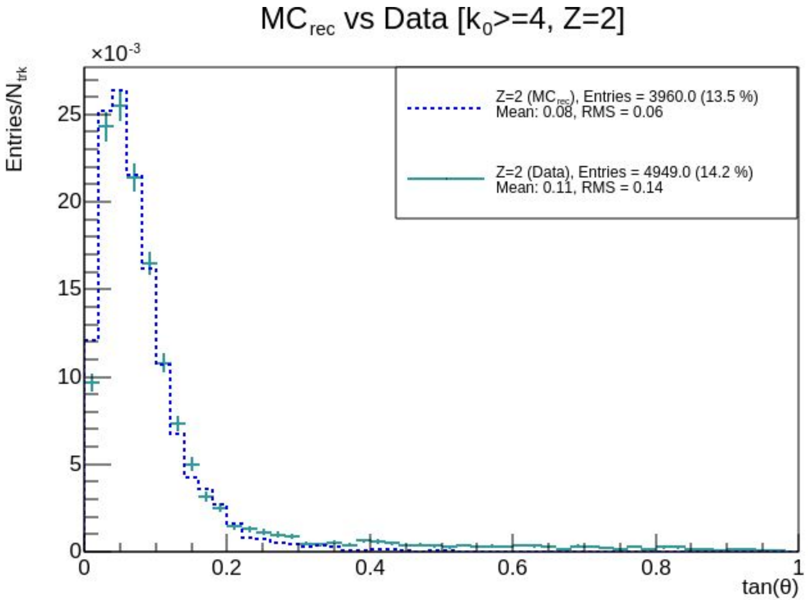
MC Cuts: track in S2, p>0.1 MeV/c, $\tan(\vartheta_x) < 0.1$, $\tan(\vartheta_y)<0.1$

Fractions calculated w.r.t. total number of trks

GSI3: Comparison between data and reconstructed MC

- Comparisons between the angular distributions (data vs reconstructed MC) show a fairly good agreement;





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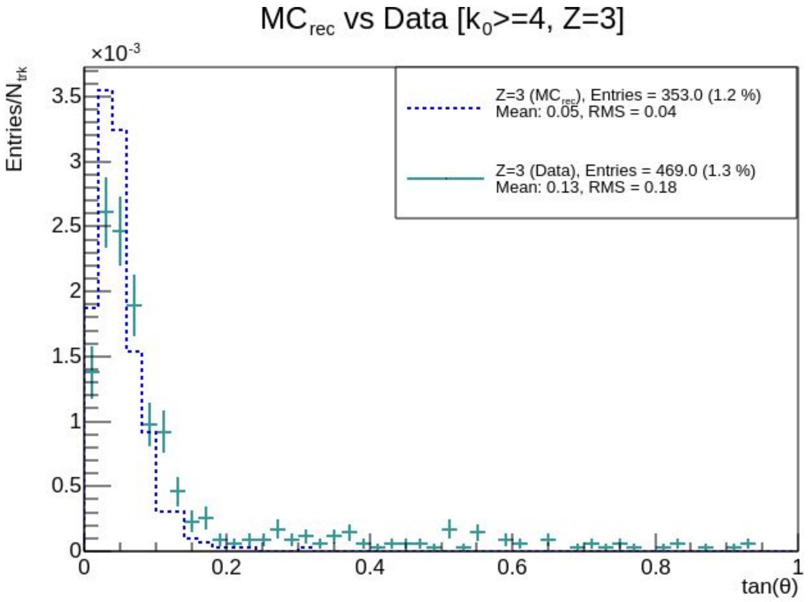

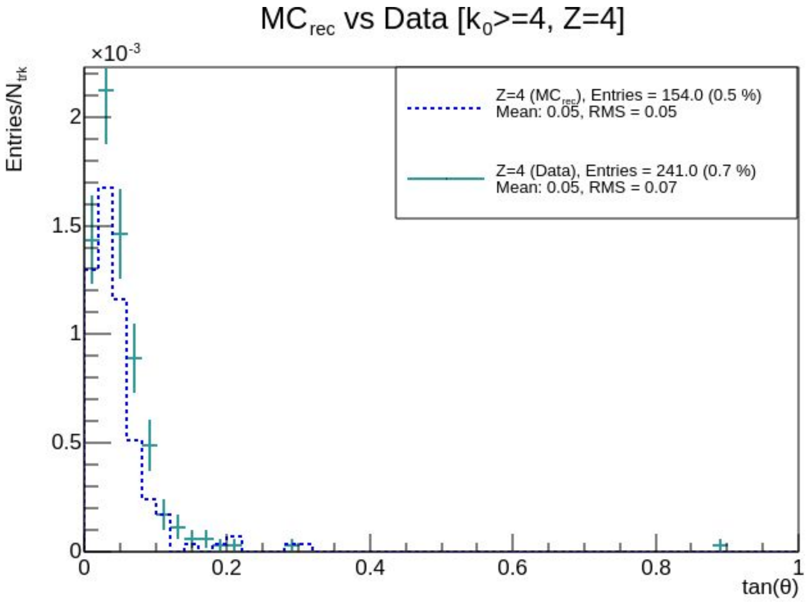

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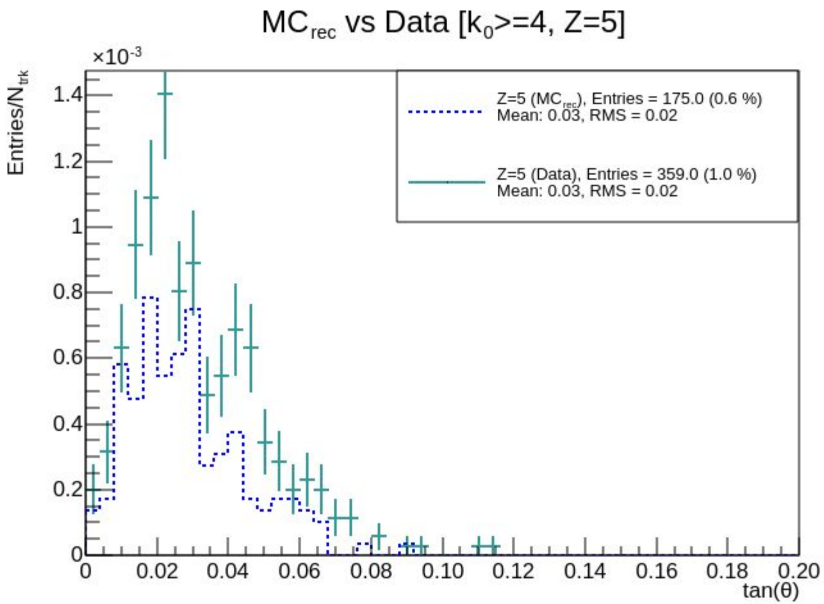


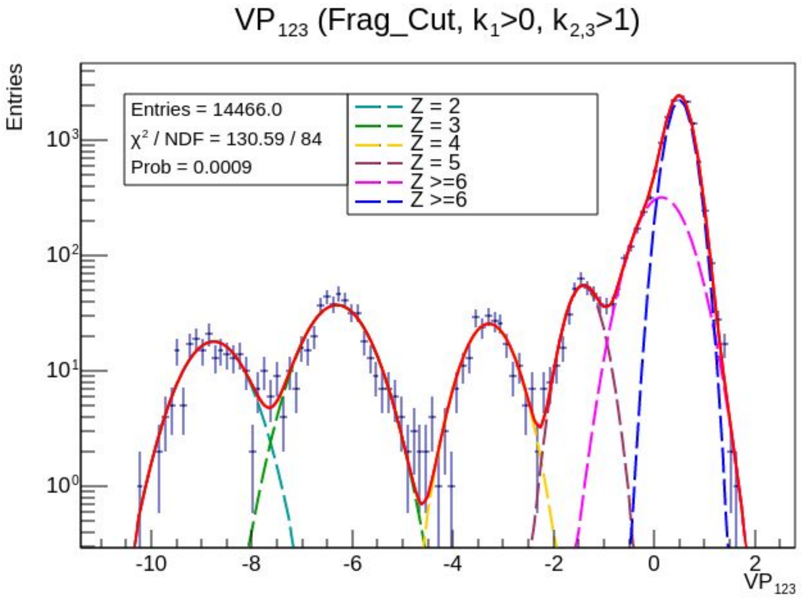
Summary

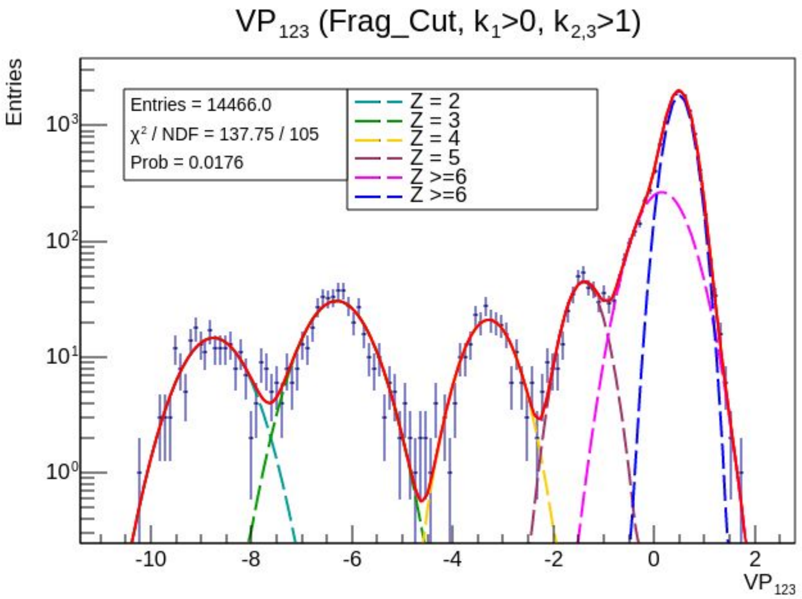
- Charge identification for GSI3 (400 MeV/n ^{16}O beam, C target) data has been completed;
    - Considering the fraction of tracks that could not be classified with VP_{012} or VP_{013}, the overall classification efficiency is approximately 99%;
- Good agreement between MC and data;
- Next: charge identification for GSI4 data;

Back-up

GSI3: PCA Error Evaluation Different Binning

- Two components: <u>systematic error</u> of the chosen fit and <u>errors of fit parameters</u>;
- The systematic component has been evaluated by repeating the fits with 3 different binnings;





GSI3: PCA Error Evaluation: VP123 & VP01

VP_{123}

Fit #	Z=2		Z=3		Z=4		Z=5		Z>=6	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
1	203	5	429	5	228	1	361	13	13244	12
2	204	3	428	4	229	1	354	10	13251	9
3	205	5	427	5	229	2	359	12	13246	11

VP_{01}

Fit #	Z=1		Z=2	
	Mean	σ	Mean	σ
1	904	27	4066	27
2	820	14	4149	14
3	818	16	4152	16

- Systematic error: (Max-Min)/2
- Gaus Fit error: σ on weighted average

Note: the populations are well separated and the different binnings do not significantly change the results

PCA: Second principal Component