UPDATE ON THE ANALYSIS OF GSI2 ^{16}O (200 MEV) ON C AND C_2H_4

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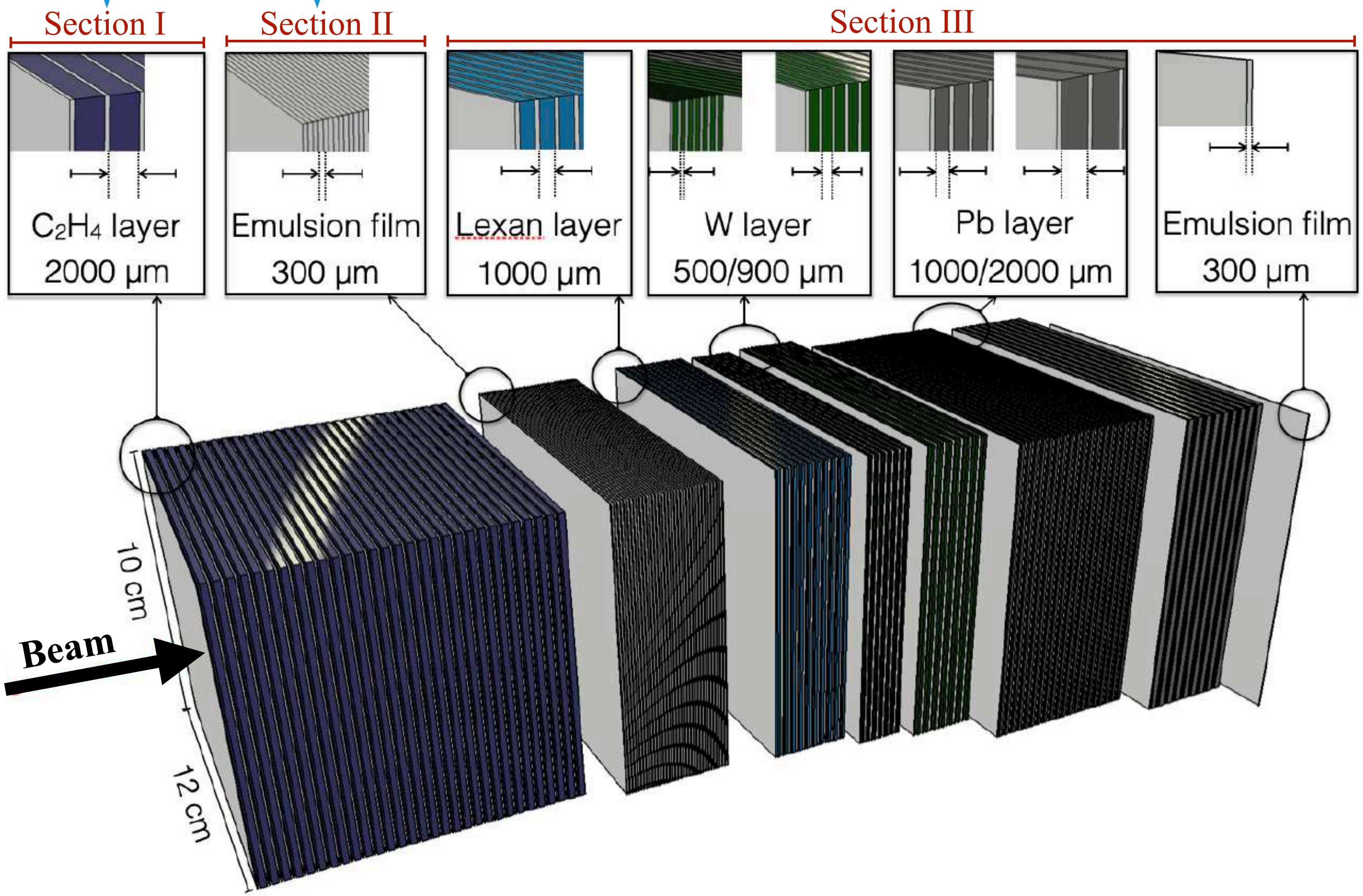
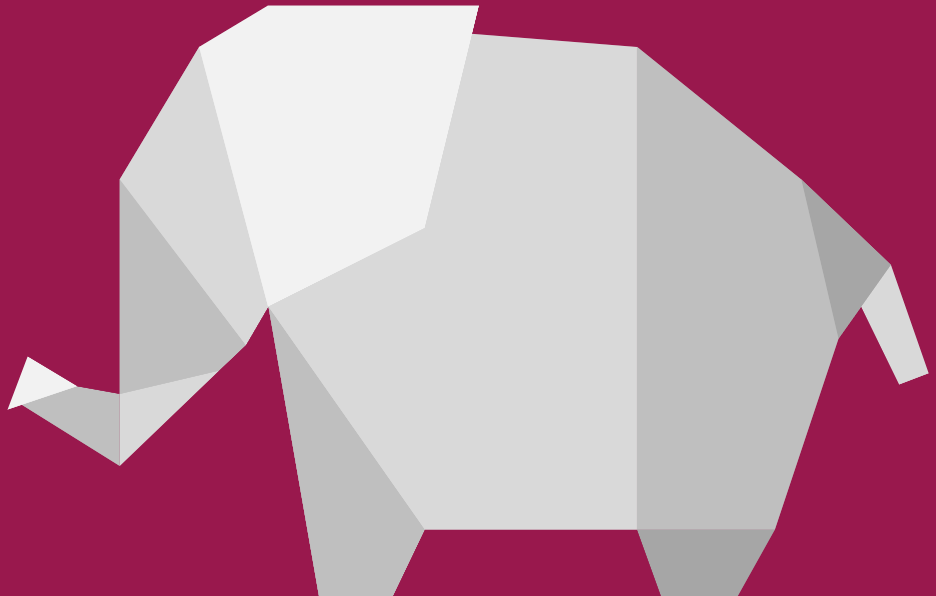
Outline

- On the path toward cross section measurement
  - Vertex reconstruction improvements
  - Comparison between true and reconstructed Monte Carlo
- Data analysis
  - Scanning Progresses
  - GSI2 vertex reconstruction: first look with improved vertex reconstruction algorithm
  - GSI1 Charge measurement and comparison with GSI2

Detector Structure



Vertex reconstruction improvements

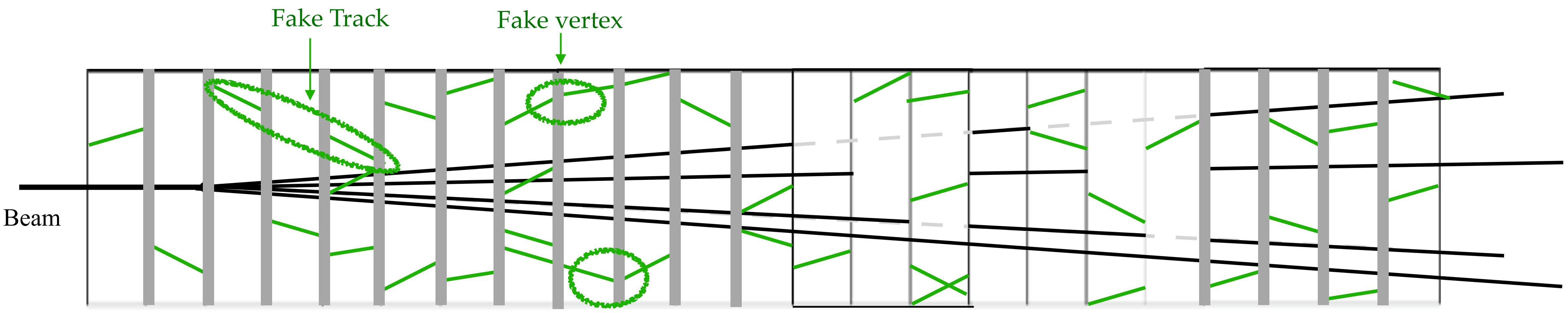


Vertexing

- Good vertices reconstruction is one of the key point to evaluate cross section
- Efficiencies for cross section measurement will be obtained:
  - comparing True and Reconstructed Monte Carlo
  - data control sample ← to do
- Reconstructed Monte Carlo has to reproduce detector response:
  - angle smearing
  - data-driven inefficiencies
  - introduction of data-driven background (see slide 6)
- Improvements of vertexing algorithm after visually inspecting many displays of Reconstruct MC: many "pathologies" now have been cured (see slides 7-11). Agreement between Reconstructed MC and True one significantly improved. Still room for further improvements
- Procedure for cross section evaluation ready

Background in Monte Carlo Simulation

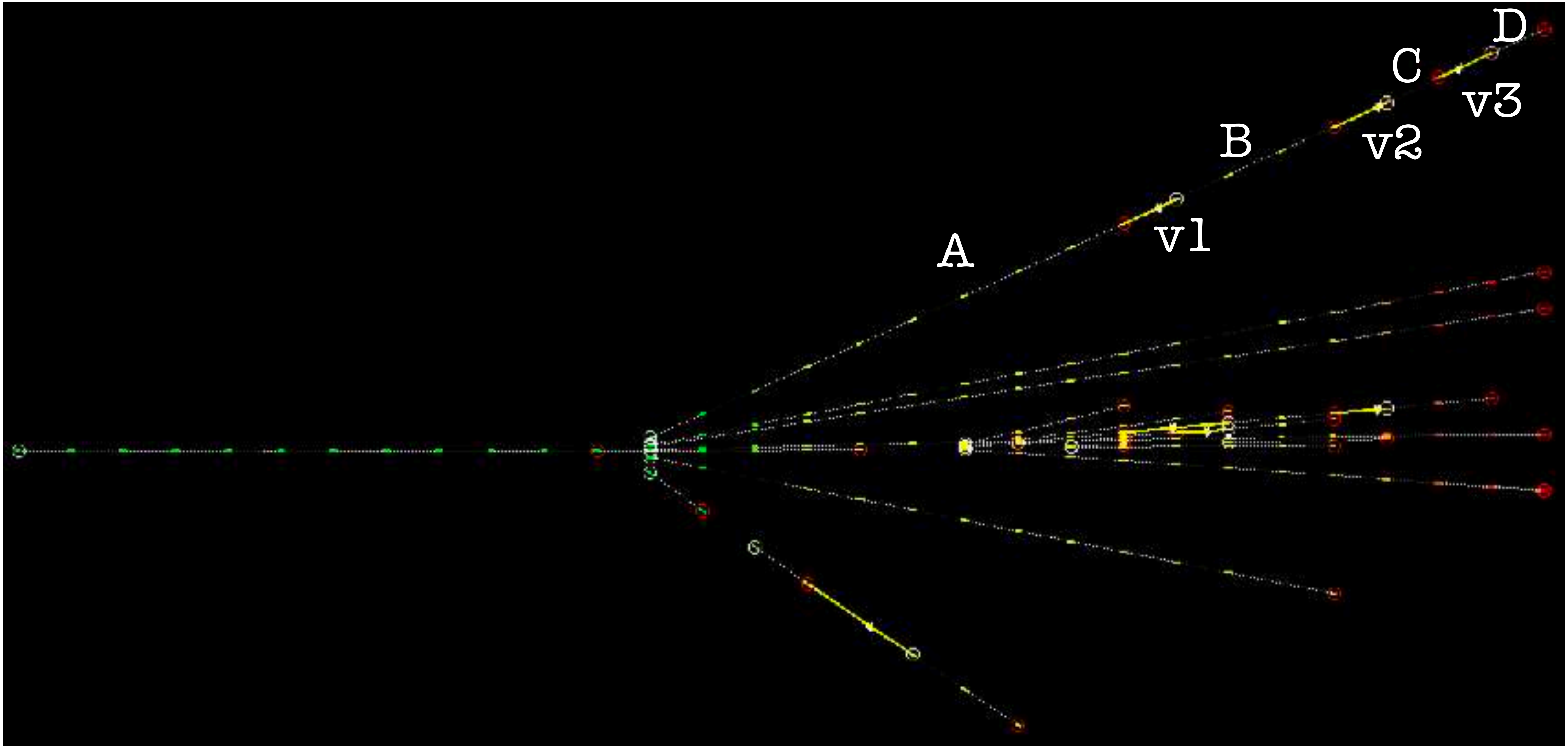
- Nuclear emulsions integrate cosmic rays since their production up to their development
- Before and after brick assembling nuclear emulsions are are are piled up without passive material in a different order with respect to the brick one. The segments due to the cosmic rays integrated during this period, therefore, should not form any track, apart from combinatorial associations (tracks 2 or 3 segments long)



Passive material not to scale

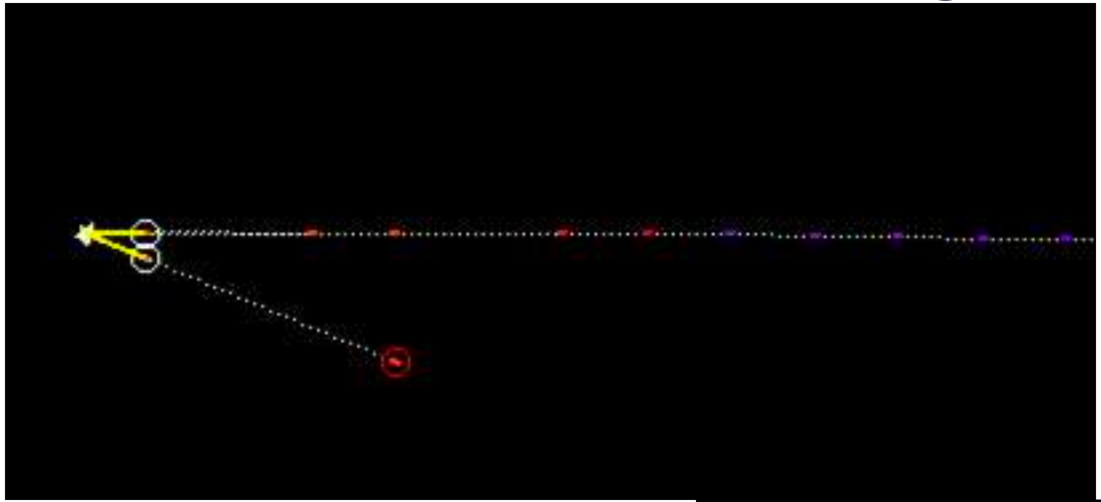
Vertexing improvements

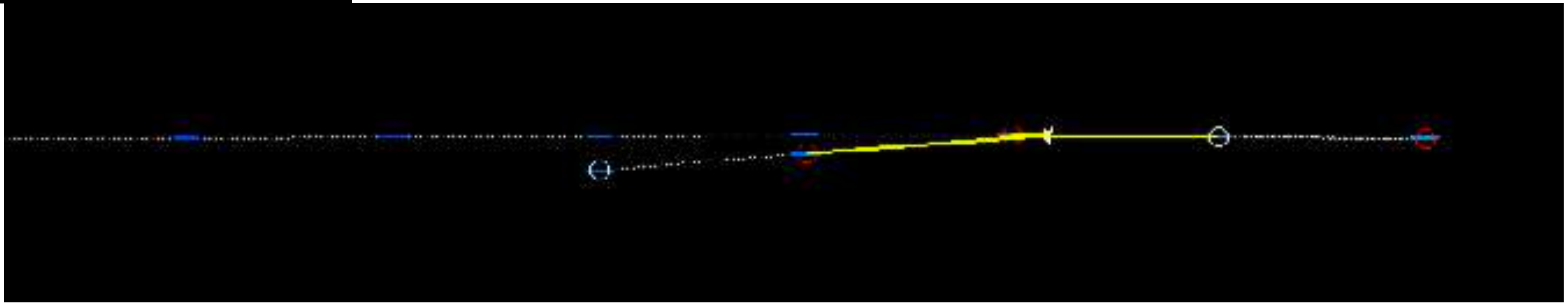
1) 2-prongs back-to-back vertices, formed due to more stringent tracking parameters, are reattached in the same track



Vertexing improvements

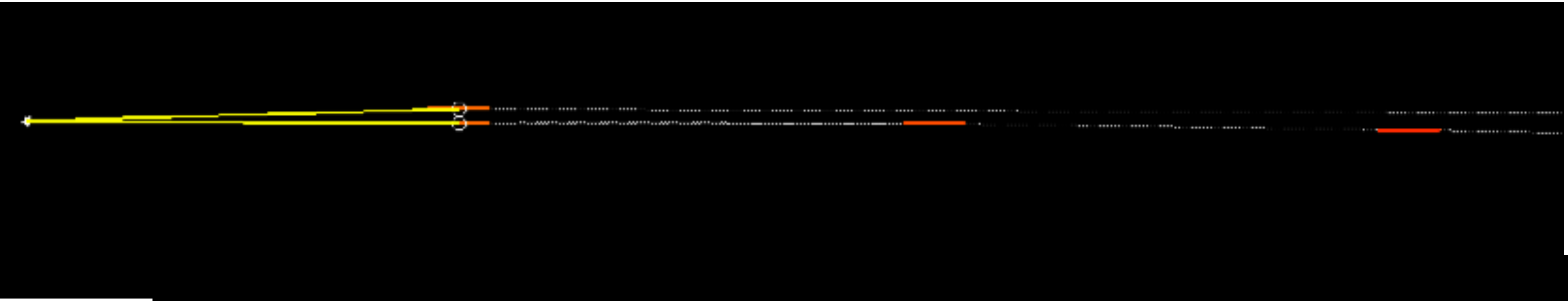
2) 2-prongs fake vertices made of one or two short tracks (n≤3)
3) 3-prongs fake vertices made of a short (n≤3) large angle track attached to an oxygen track which was split into two pieces. Short track discarded and long track becomes a a single track

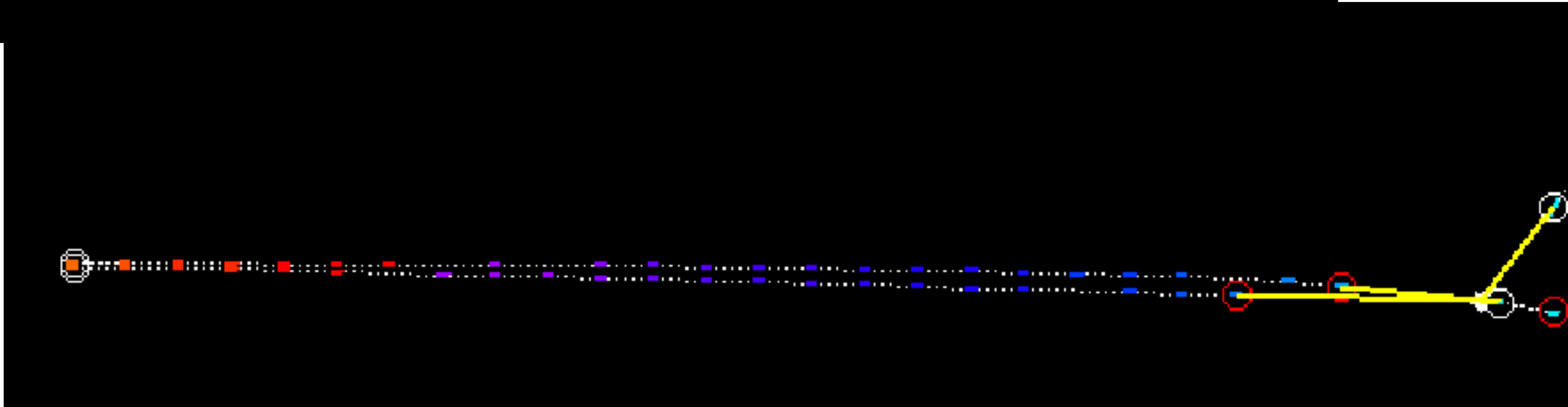




Vertexing improvements

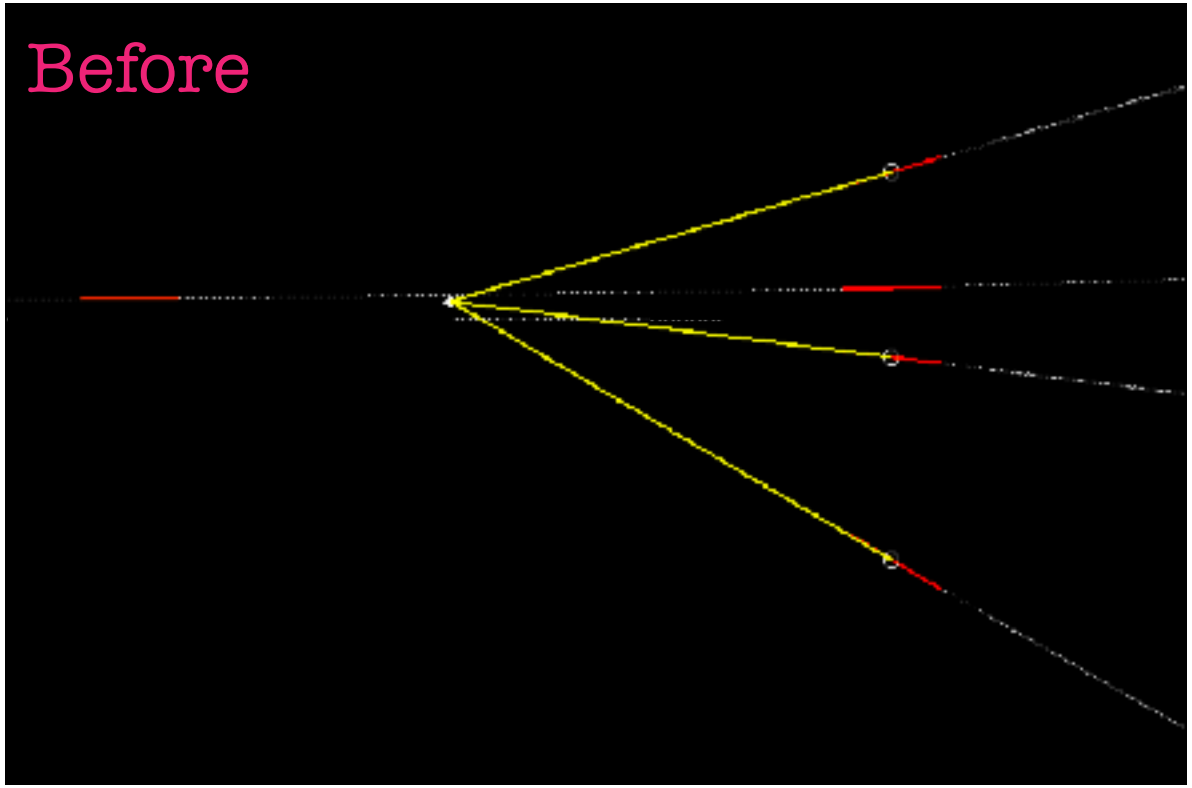
4) Vertices made of two oxygen tracks discarded
5) Two oxygens entering the same vertex: the one with largest impact parameter is removed

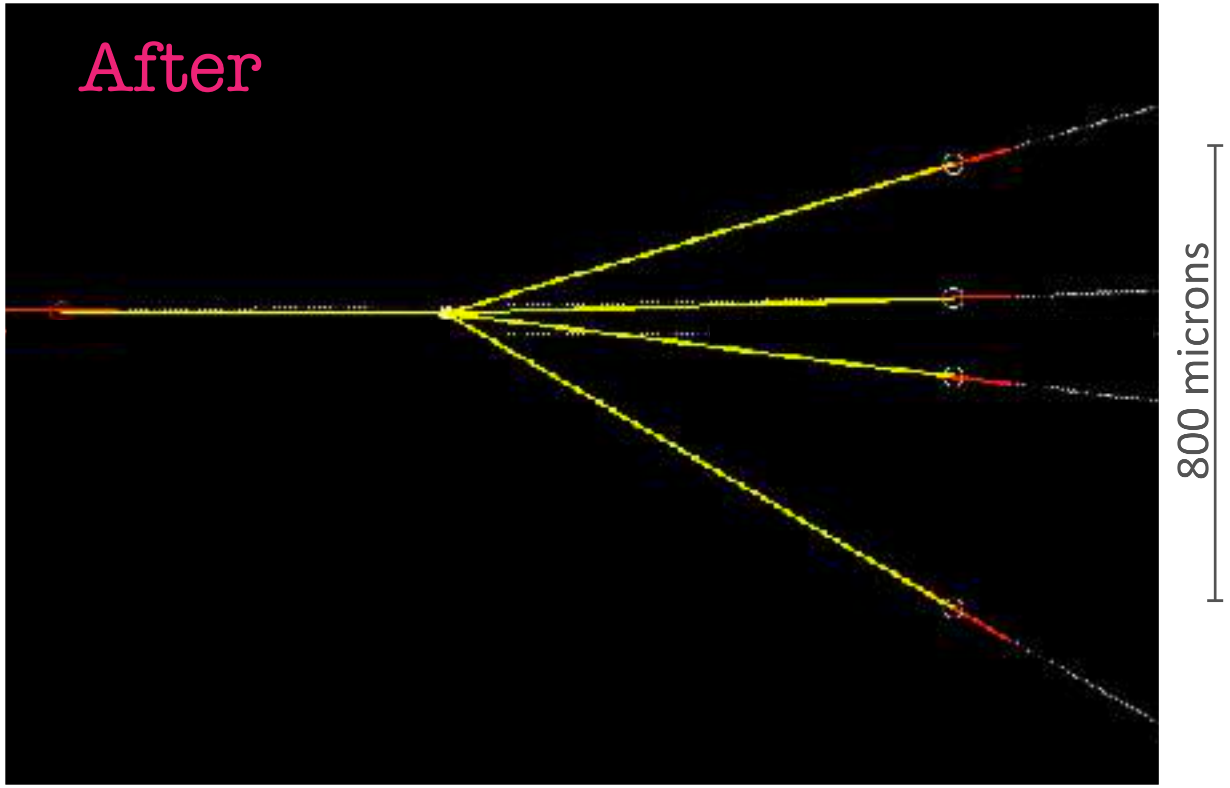




Vertexing - improvements

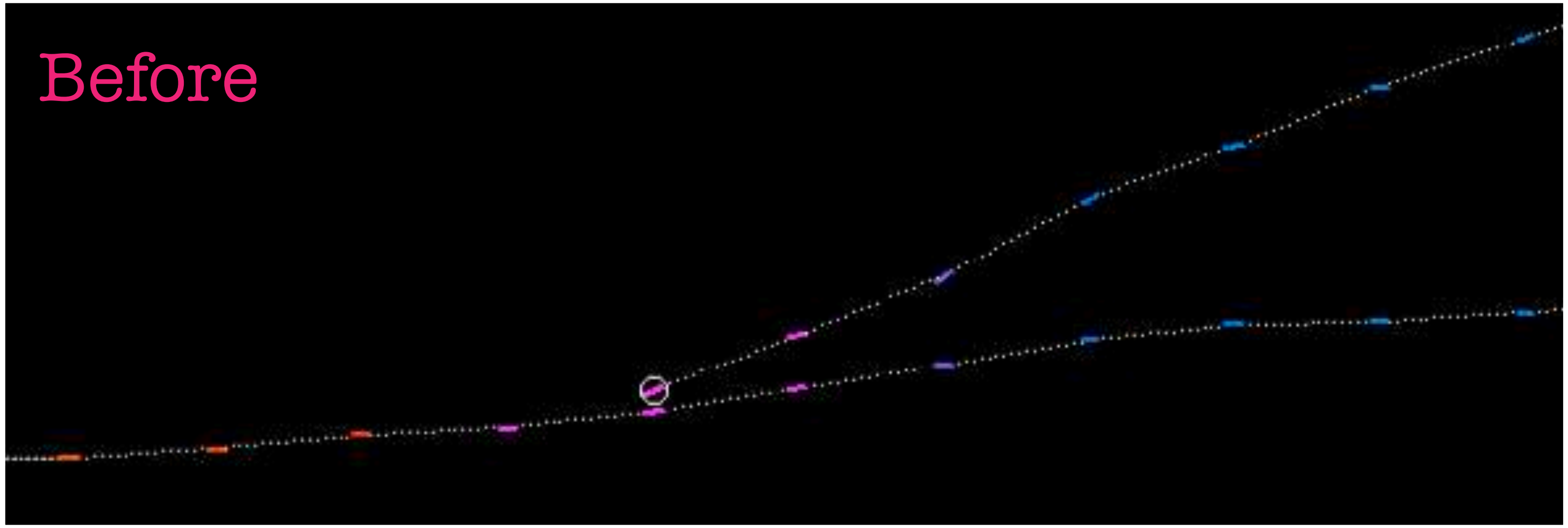
6) Vertices without oxygen track: beam track is reconstructed as penetrating due to very similar angle of a daughter track. The correct topology is restored
7) Search for extra daughters

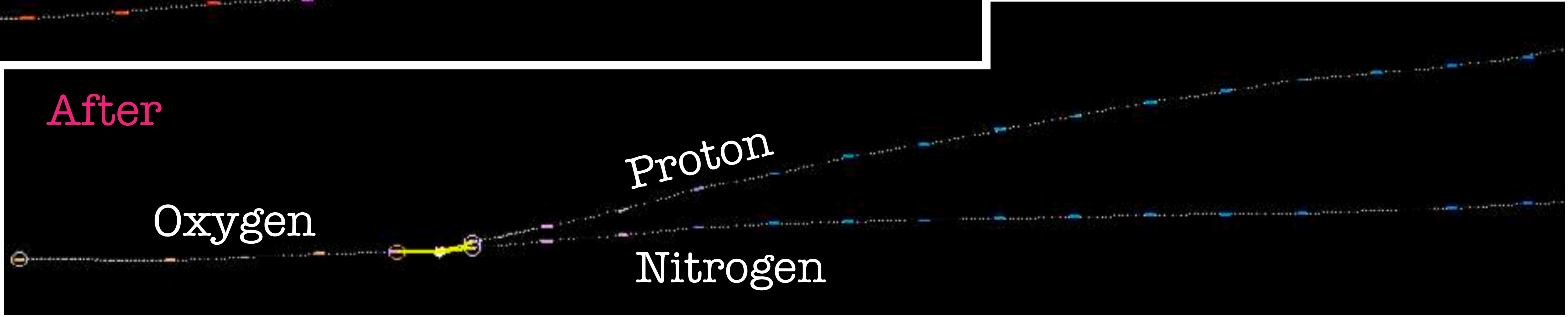




Vertexing - improvements

8) Oxygen going into nitrogen with the emission of a proton.
Due to very similar angle Oxygen and Nitrogen are reconstructed as one track. Search for protons with small impact parameter to the beam track which go beyond the Bragg Peak.





Some results on "improved" vertices (Reconstructed MC)

	GSI1	GSI2	
Starting from	13182	11350	Number of vertices to which the algorithm is applied
Ending with	8667	7006	Number of vertices after algorithm
Beam found	1824	1293	beam tracks found after improvement #6 (slide 10)
Extra daughters	1128	769	daughter tracks found after improvement #7 (slide 10)
tracks merged	1895	1426	tracks merged after improvements #1 (slide 7) and #3 (slide 8)
Vtx purity	70%	77%	% of tracks belonging to the main MC Event ID
n≥3	5970	5282	Number of vertices with at least 3 tracks

- First version of the algorithm was really slow (days…)
- New version running within few minutes!

Some results on “improved” vertices (DATA)

PRELIMINARY

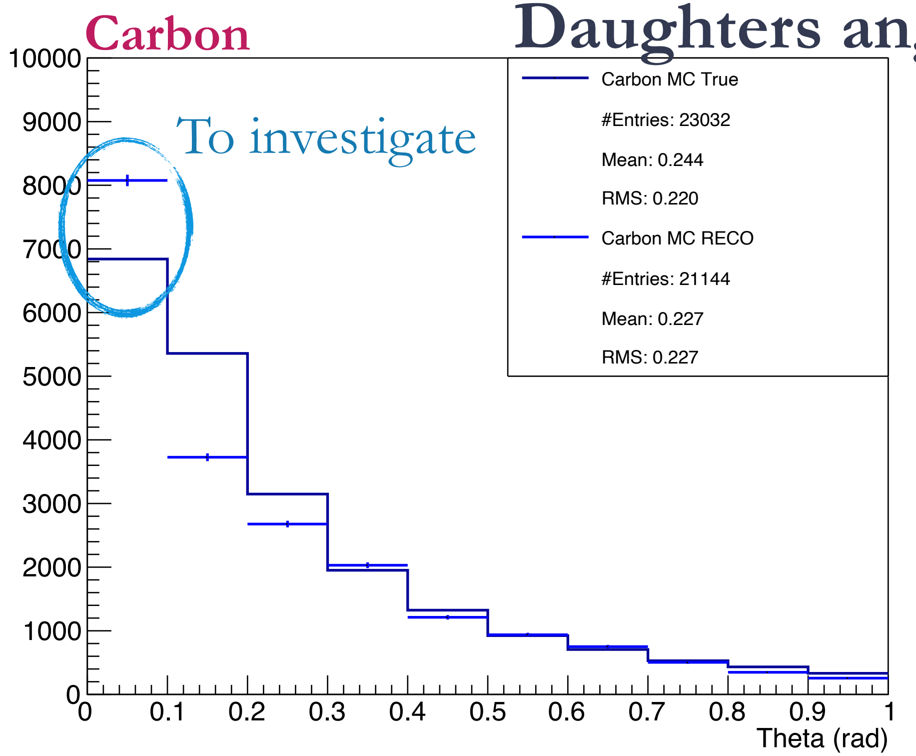
	GSI2 Reco	GSI2 Data	
Starting from	11350	16483	Number of vertices to which the algorithm is applied
Ending with	7006	9523	Number of vertices after algorithm
Beam found	1293	1878	beam tracks found after improvement #6 (slide 10)
Extra daughters	769	1005	daughter tracks found after improvement #7 (slide 10)
tracks merged	1426	1533	tracks merged after improvements #1 (slide 7) and #3 (slide 8)
$n \geq 3$	5282	6372	Number of vertices with at least 3 tracks

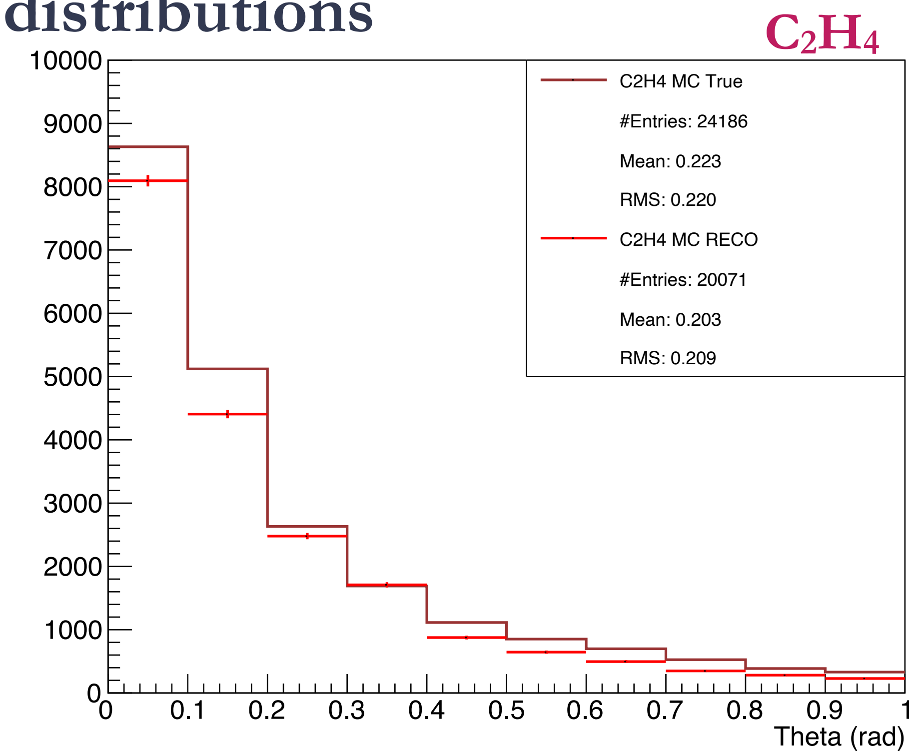
normalised to the same beam particles

MC True vs Reconstructed

	GSI1	GSI2
Oxygen beams	19375	
MC True vertices	5031	5875
MC Reco vertices (n>=3)	5970	5282

Daughters angular distributions





Data analysis

Charge identification paper

Article accepted on Open Physics!

Research Article

Open Access

Charge identification of fragments with the emulsion spectrometer of the FOOT experiment

Abstract:

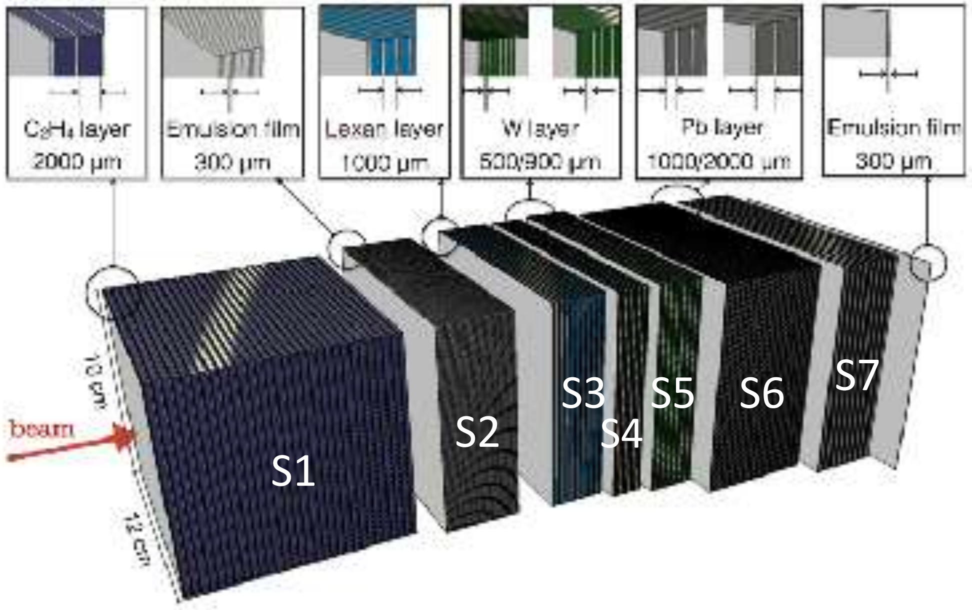
Keywords:

PACS:

1 Introduction

Scanning Progress

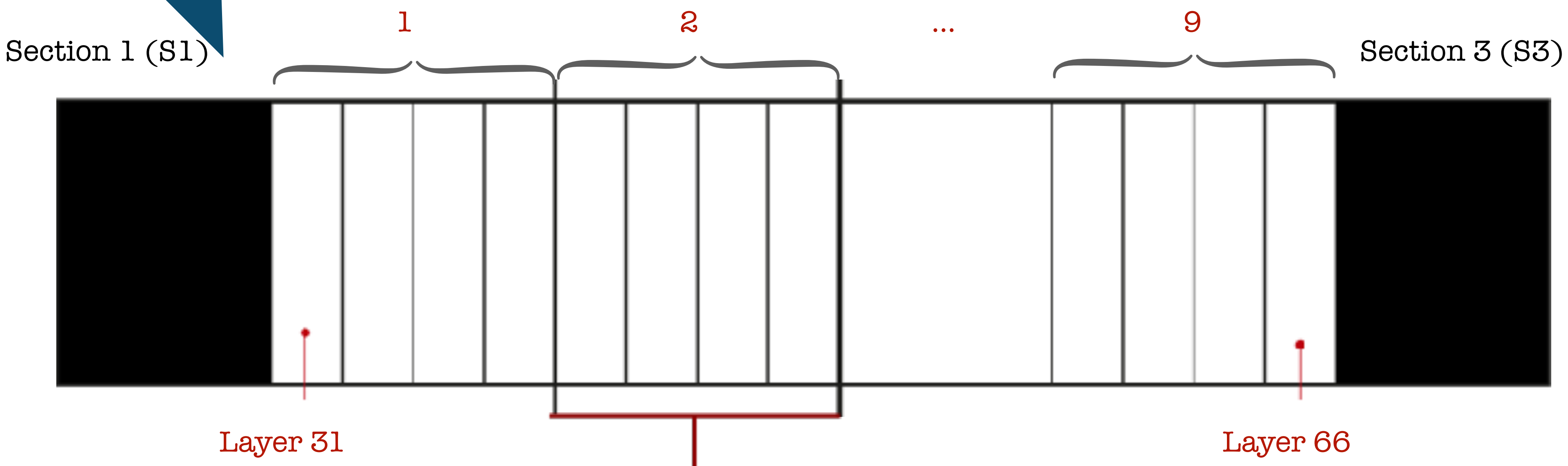
TARGET / BEAM	Oxygen 200 MeV/n (2019)	Oxygen 400 MeV/n (2019)	Carbon 700MeV/n (2020)
Carbon	GSI1	GSI3	GSI5
Polyethylene	GSI2	GSI4	GSI6

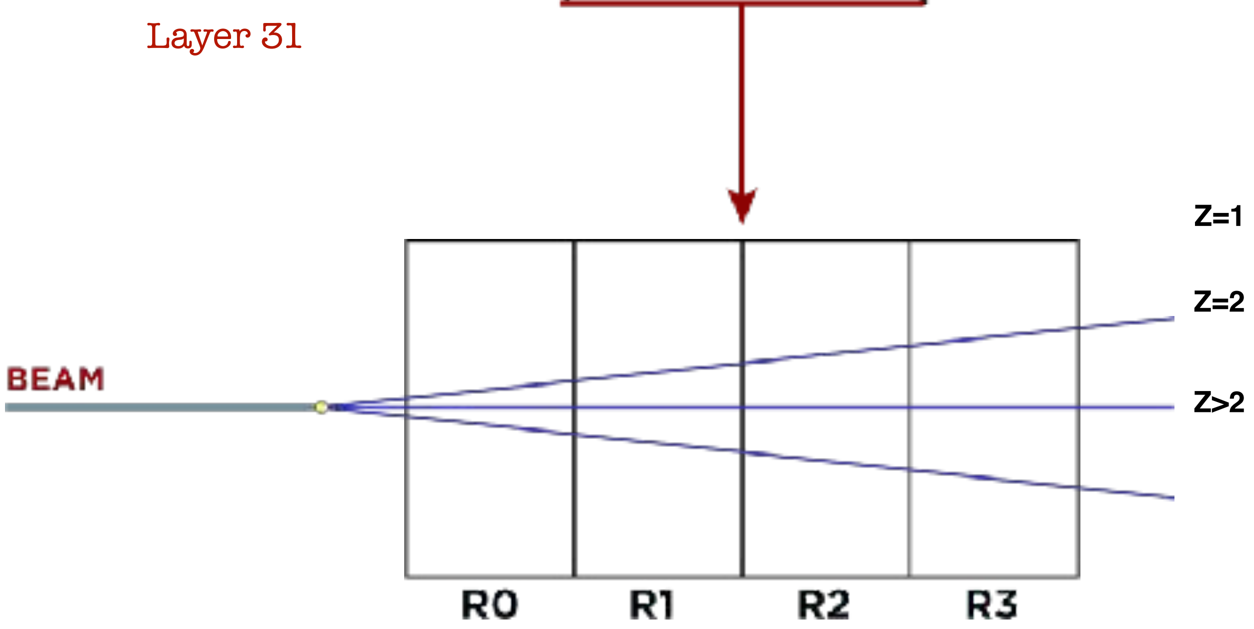


- 2019 (GSI1, GSI2, GSI3, GSI4):
  - scanning: 100%
  - alignment:
    GSI1: 100%
    GSI2: 100%
    GSI3: 47%
    GSI4: 47%
  - tracking:
    GSI2: S1+S2 completed, S3 (=S3+S4+S5+S6+S7) started
    GSI1: S1 quality checks ongoing
    S2 completed
- 2020 (GSI5, GSI6):
  - scanning: 328/328 (100%)

GSI1 Charge Measurement

Structure of Section 2 (S2)

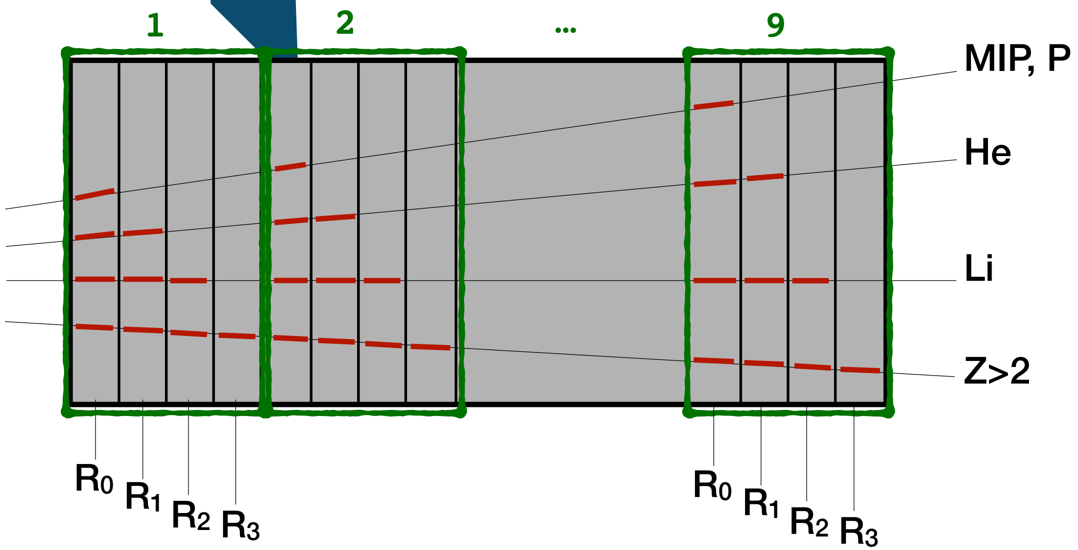


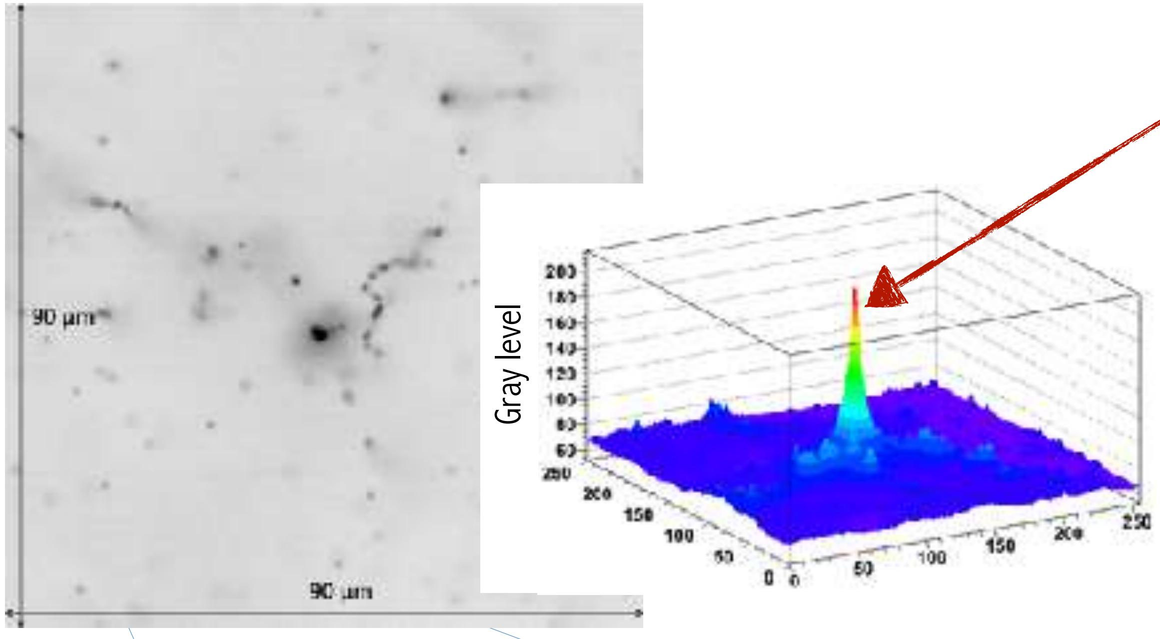


Emulsions in S2 underwent to **different thermal treatments**

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

Variables used



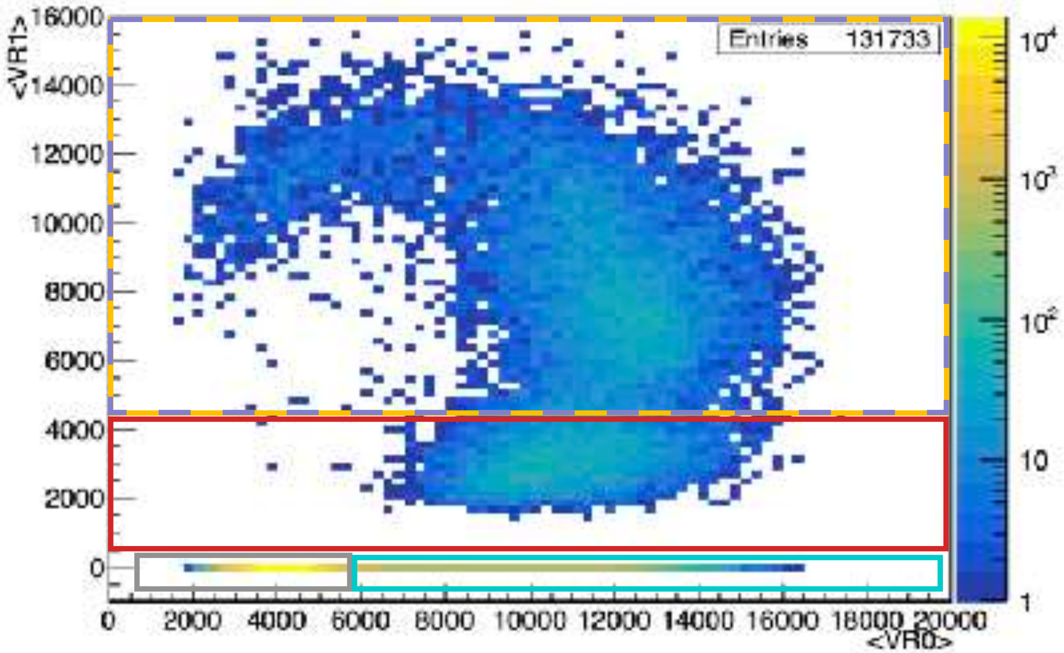


Each thermal treatment erase totally or partially the track's segments, depending on its ionization.

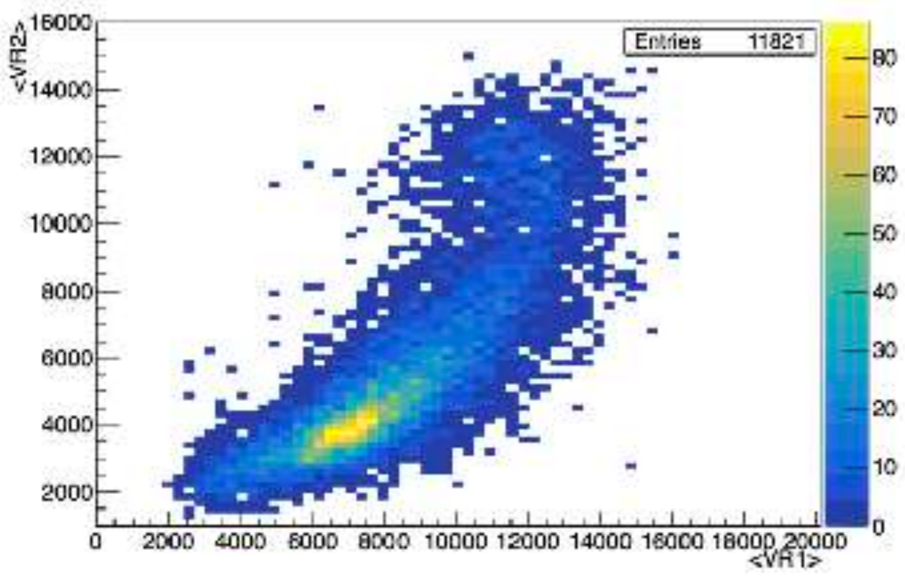
For each track the following variables are evaluated:

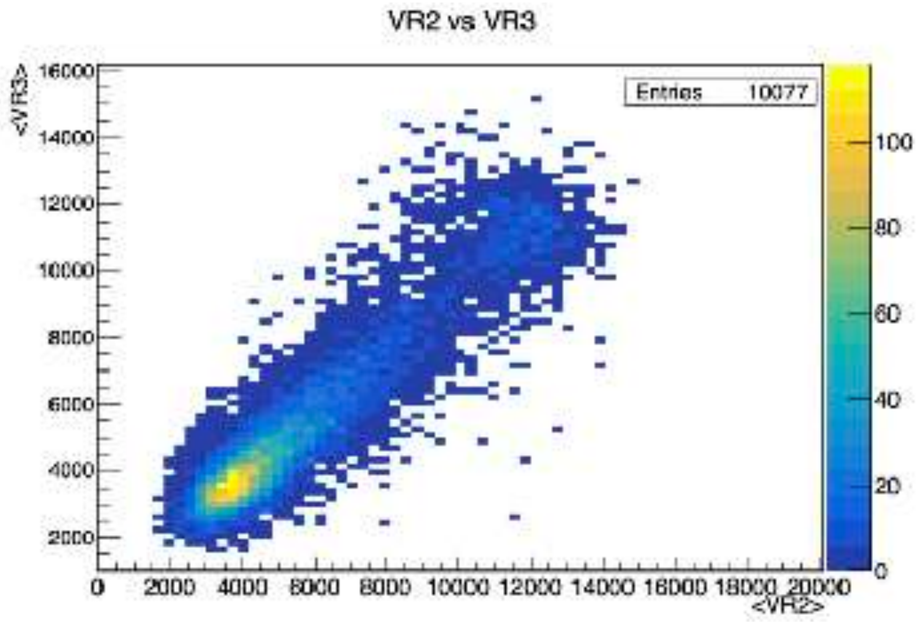
- tanθ: the tangent of the inclination of most upstream fitted track segment w.r.t. the Z axis
- NRx: the number of base-tracks belonging to the track for each set of thermal treatments *Rx*, with $x \in \{0,1,2,3\}$
- VRx: for each base-track, a variable named "volume" is defined as the sum of the pixel brightness and expressed in arbitrary units related to particles' ionization
- $\langle \mathrm{VRx} \rangle = \frac{\sum_{NRx} VRx}{NRx}$

Charge Measurement

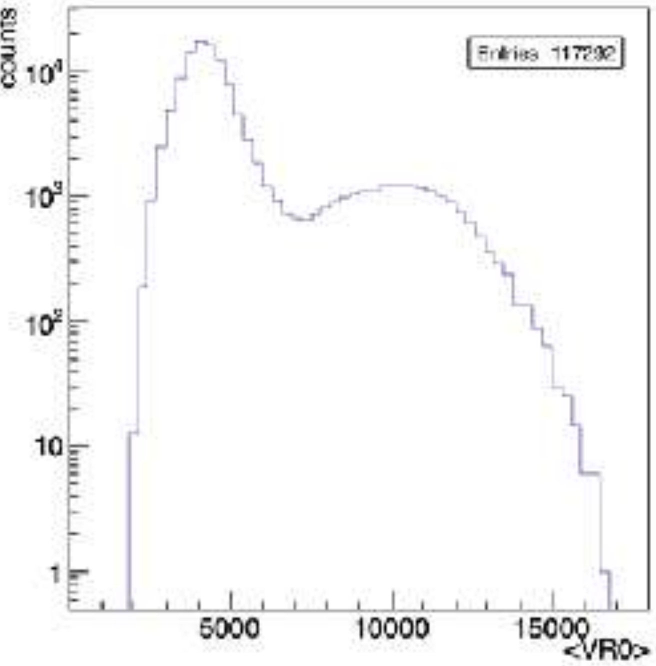


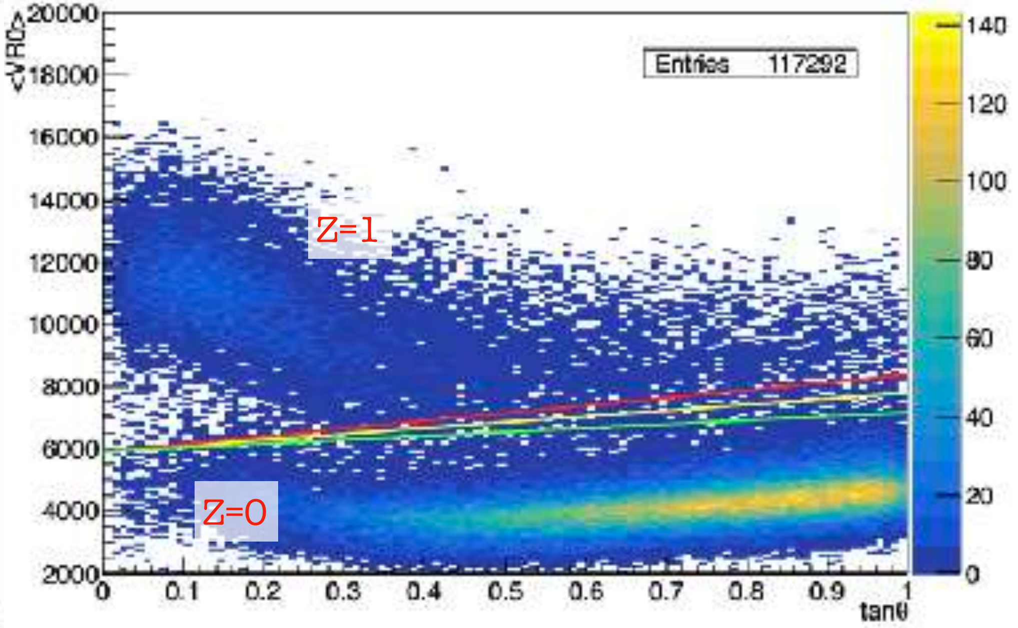
- Combining the four ⟨VRx⟩ variables we can distinguish the particles' charge:
  - ➡ Z≤2: sharp cuts on VR0 and VR1
  - ➡ Z≥2: Principal Components Analysis

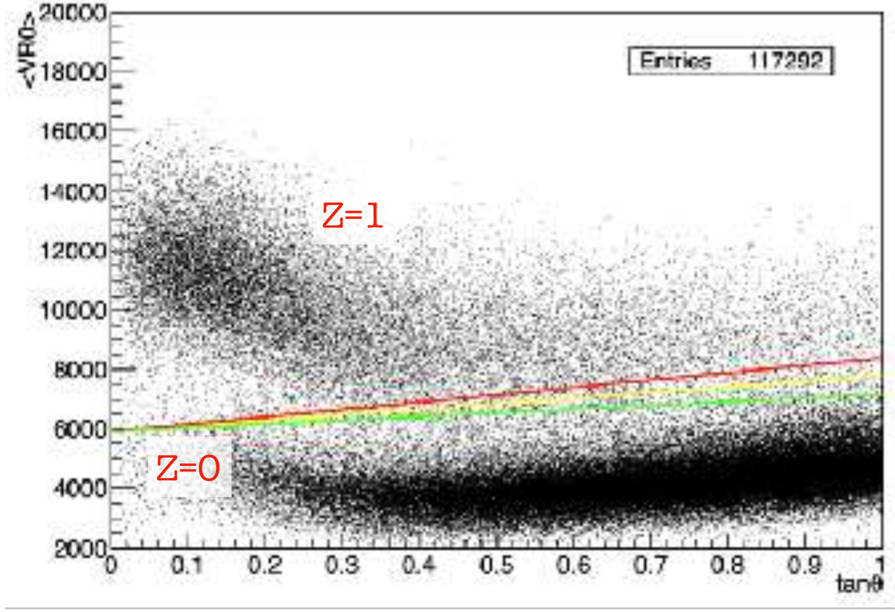




Cosmic Rays and High Energy Z=1

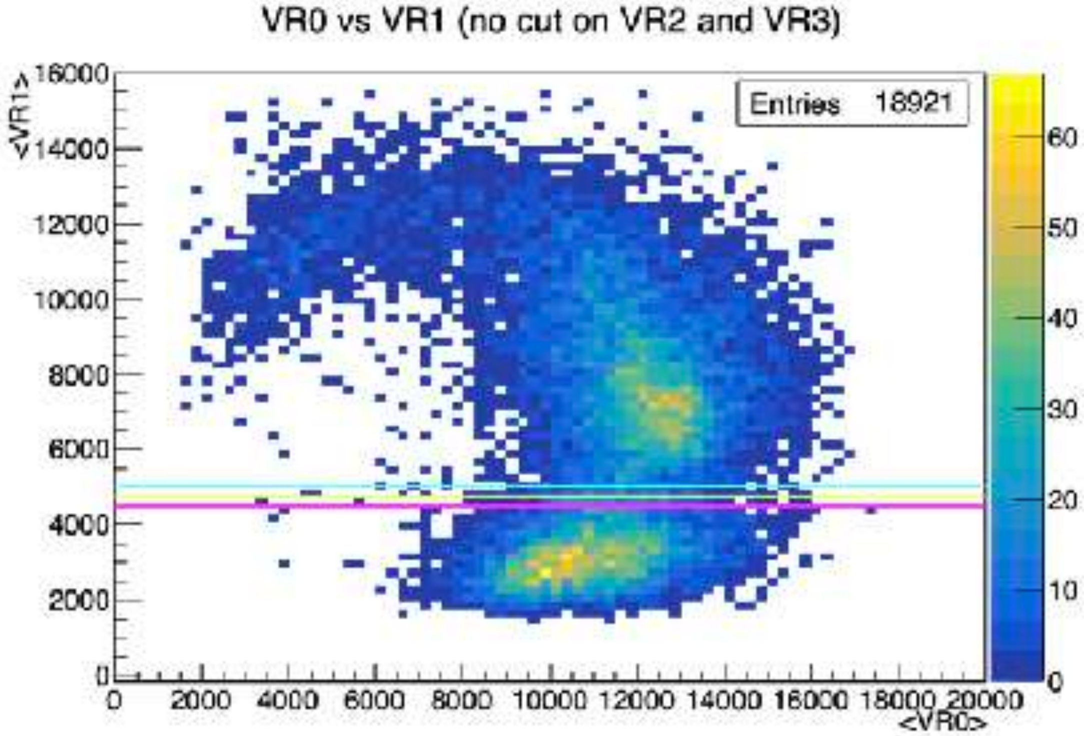


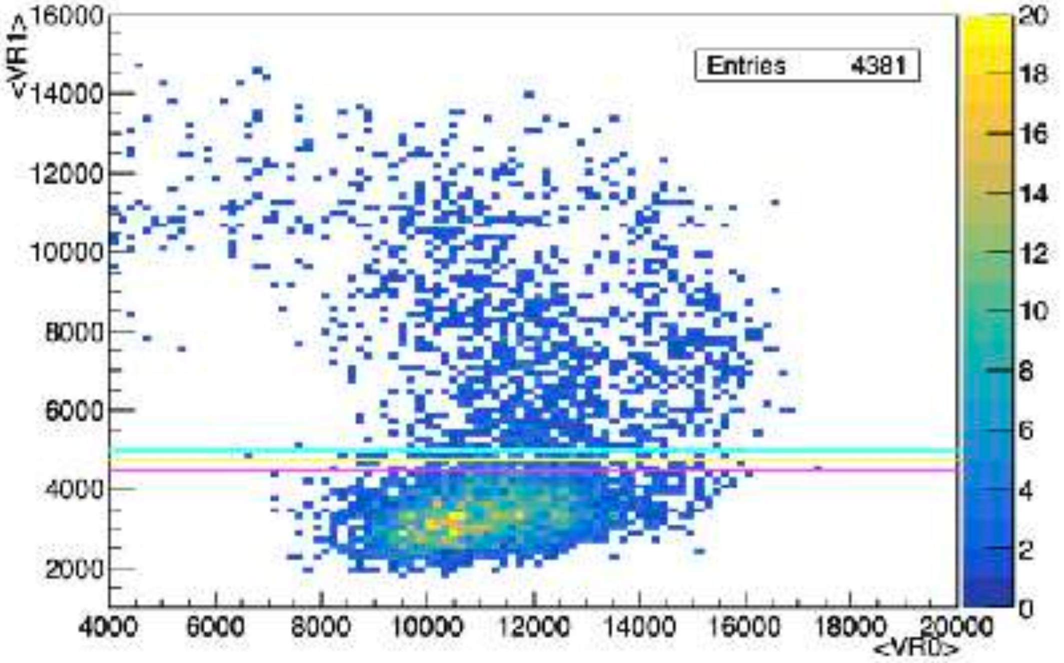




- **Cosmic Rays:**
  - **line0a: ⟨VR0⟩** <1285.71*tanθ+5900 & ⟨VR0⟩!=0&NR1<2&NR2<0&NR3<0
  - **line0b:** ⟨VR0⟩< 1892.86*tanθ+5900 & ⟨VR0⟩!=0&NR1<2&NR2<0&NR3<0
  - **line0c:** ⟨VR0⟩< 2500*tanθ+5900 & ⟨VR0⟩!=0&NR1<2&NR2<0&NR3<0
- **High energy Z=1**: ⟨VR0⟩≥line0* &&NR1<2&&NR2<2&&NR3<2

Z=1 Low energy





- **Low energy Z=1:**
  - line1a: $\langle VR0\rangle \geq 0 \&\& 0 < \langle \mathbf{VR1}\rangle \leq \mathbf{4500} \&\& NR2 < 2 \&\& NR3 < 2$
  - line1b: $\langle VR0\rangle \geq 0 \&\& 0 < \langle \mathbf{VR1}\rangle \leq \mathbf{4750} \&\& NR2 < 2 \&\& NR3 < 2$
  - line1c: $\langle VR0\rangle \geq 0 \&\& 0 < \langle \mathbf{VR1}\rangle \leq \mathbf{5000} \&\& NR2 < 2 \&\& NR3 < 2$
- **High energy Z=2**: $\langle VR1\rangle \geq line1^{*} \&\& NR2 < 2 \&\& NR3 < 2$

Error Evaluation for Sharp Cuts

line0a / line1a		
Z	# trks	% on total
Cosmic	96462	79.3%
1	23594	19.4%
2	1617	1.3%
Tot	121673	

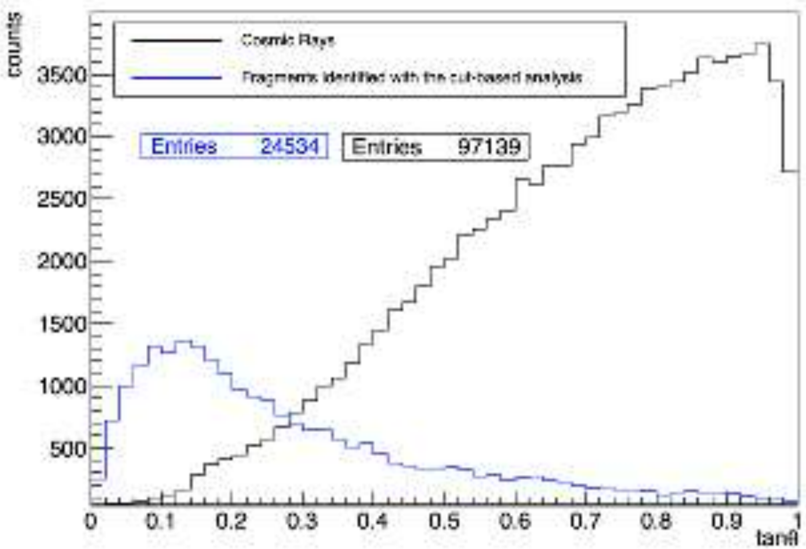
line0c / line1a		
Z	# trks	% on total
Cosmic	97752	80.3%
1	22304	18.3%
2	1617	1.3%
Tot	121673	

line0a / line1c		
Z	# trks	% on total
Cosmic	96462	79.3%
1	23835	19.6%
2	1376	1.1%
Tot	121673	

line0c / line1c		
Z	# trks	% on total
Cosmic	97752	80.3%
1	22545	18.5%
2	1376	1.1%
Tot	121673	

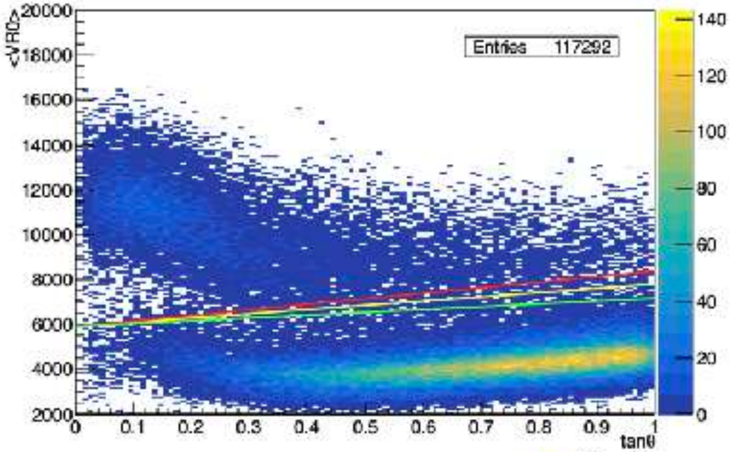
Results

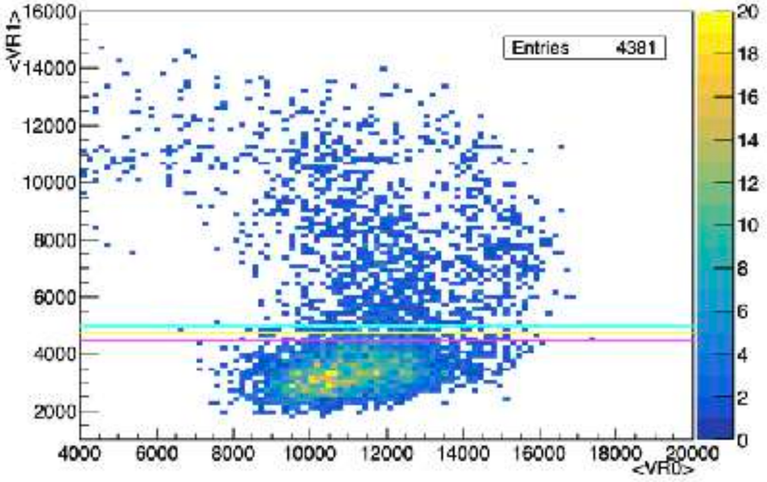
	MEAN line0b / line1b		ERROR (Max-Min)/2	
Z	# trks	% on total	# trks	% on total
Cosmic Rays	97139	80%	645	1%
Z=1	23048	19%	766	3%
Z=2	1486	1%	121	8%
TOT	121673			



Comparison between GSI2 and GSI1

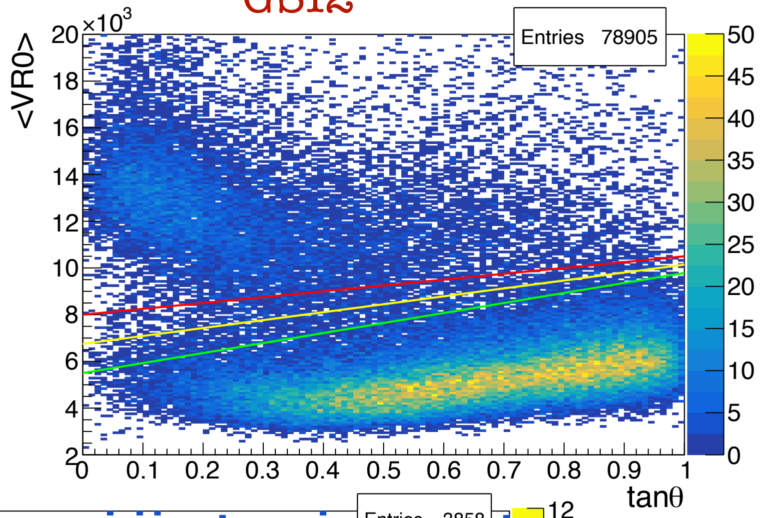
GSI1

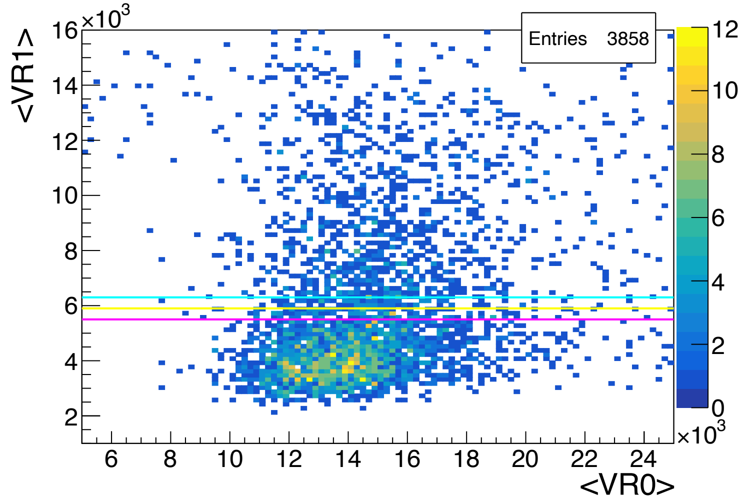




Z	#trks	Result	Systematic err
1	23048	94%	3.3%
2	1486	6%	8.1%

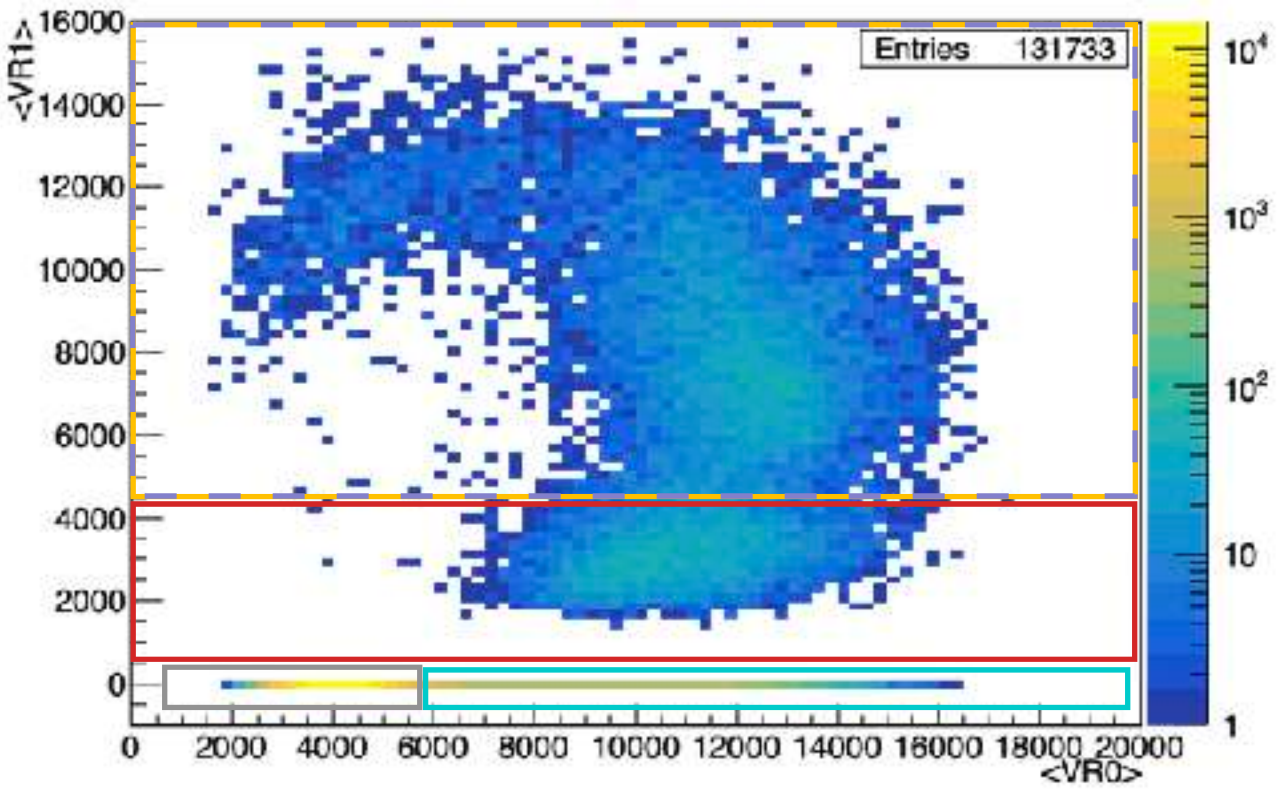
GSI2





Z	#trks	Result	Systematic err
1	21199	94%	7.8%
2	1438	6%	11.2%

Summary Charge Measurement Z≤2



- **Z=0:** 0<⟨VR0⟩< 3392.86*tanθ+6750 & NR1<2 & NR2<2 & NR3<2
- **High energy Z=1:** ⟨VR0⟩ ≥3392.86*tanθ+6750 & NR1<2 & NR2<2 & NR3<2
- **Low energy Z=1:** ⟨VR0⟩≥0 & 0<⟨VR1⟩≤4750 & NR2<2 & NR3<2
- **High energy Z=2:** ⟨VR1⟩>4750 & NR2<2 & NR3<2

- **Z≥2: at least 3 VRx → Principal Components Analysis**

Principal Components Analysis (Pca)

Ref: https://root.cern.ch/doc/master/classTPrincipal.html

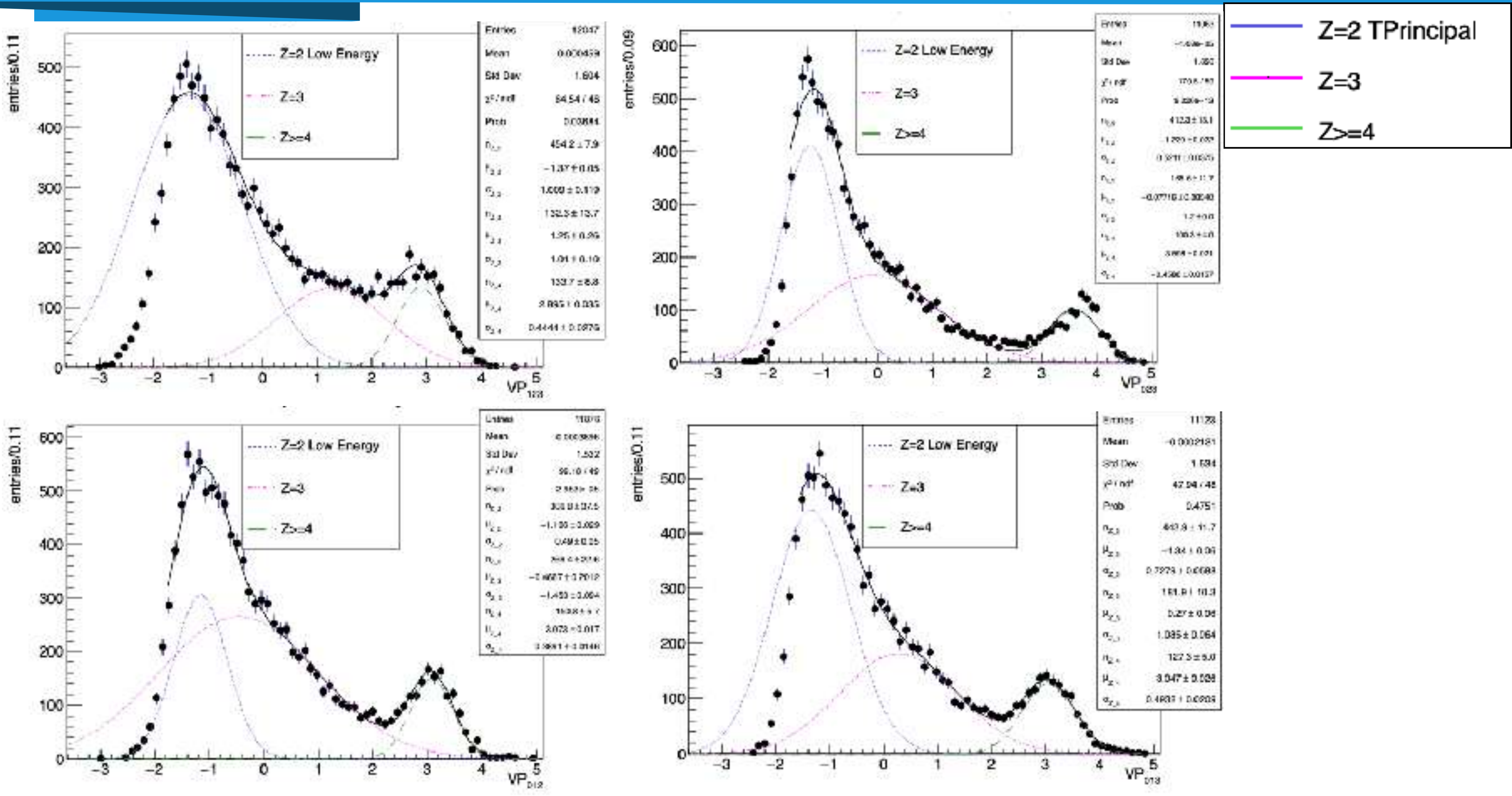
- Request: at least 3 $\langle VRx \rangle$
- Four different variables have been created:
  - $VP_{123} = a \cdot \langle VR1 \rangle + b \cdot \langle VR2 \rangle + c \cdot \langle VR3 \rangle$
  - $VP_{023} = d \cdot \langle VR0 \rangle + e \cdot \langle VR2 \rangle + f \cdot \langle VR3 \rangle$
  - $VP_{013} = g \cdot \langle VR0 \rangle + h \cdot \langle VR1 \rangle + i \cdot \langle VR3 \rangle$
  - $VP_{012} = l \cdot \langle VR0 \rangle + m \cdot \langle VR1 \rangle + n \cdot \langle VR2 \rangle$

Given the value of VP_{xxx} we assign Z according to the probability provided by the three gaussian distributions (see next slide)

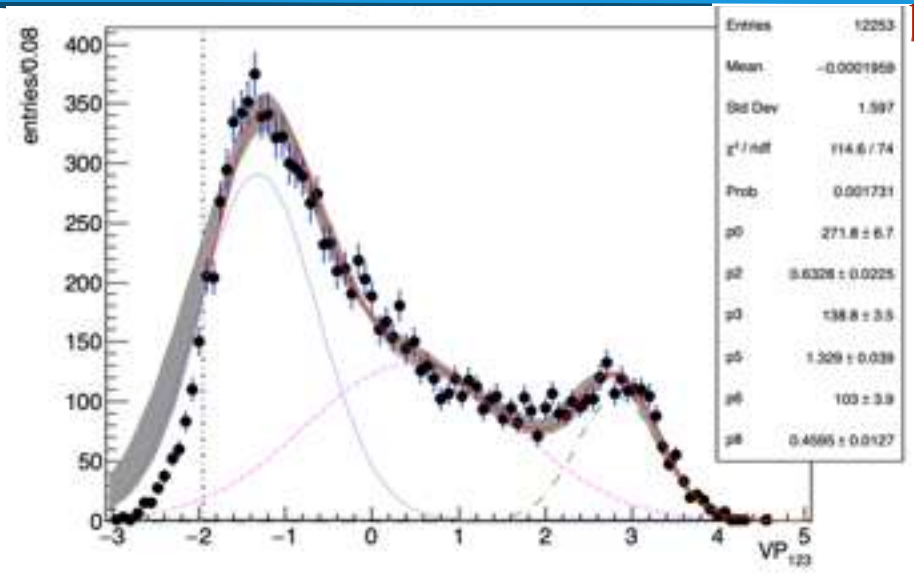
Assigned with PCA

Z	#	%
VP_{123}	8772	88.4%
VP_{012}	840	8.5%
VP_{013}	182	1.8%
VP_{023}	134	1.3%

VP_xxx Fits


Z=2 TPrincipal
Z=3
Z>=4
Z=2 Low Energy
Z=3
Z>=4
entries/0.11
entries/0.09
VP
Entries
Mean
Std Dev
Prob

VP_{123} Fits - Error evaluation

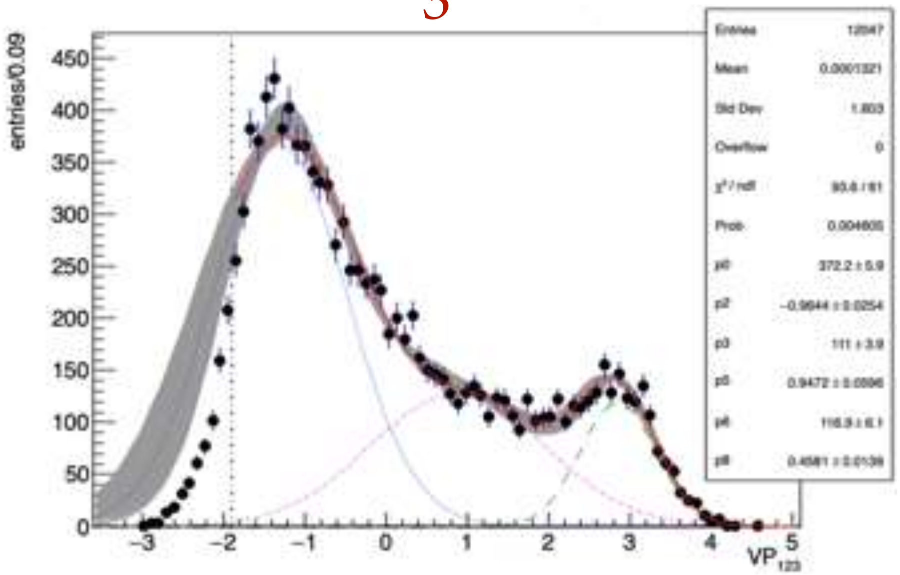


1

N trials	13285

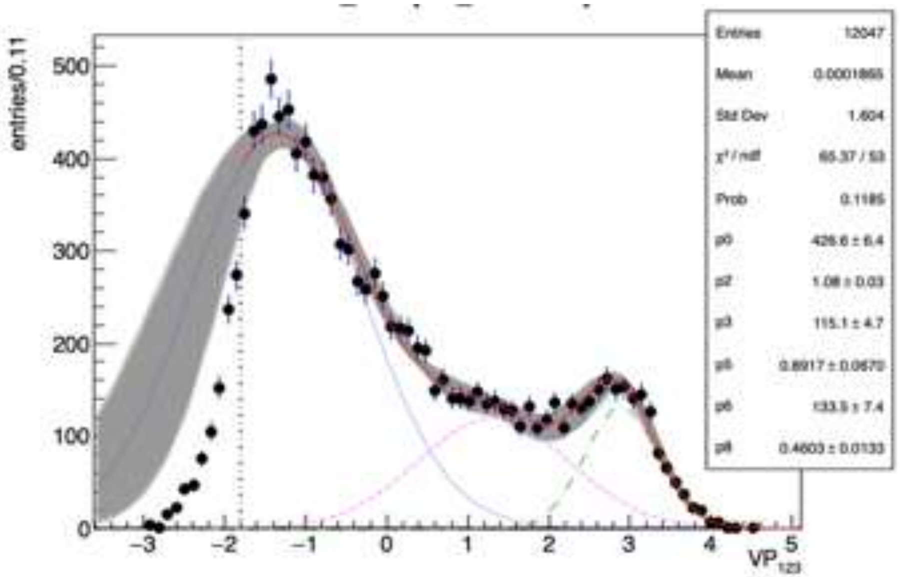
Z TPr	Mean	St. Dev
2	51.78%	5.85%
3	37.52%	5.90%
4	10.70%	0.49%

3



N trials	13162

Z TPr	Mean	St. Dev
2	63.46%	4.68%
3	26.19%	4.68%
4	10.35%	0.59%



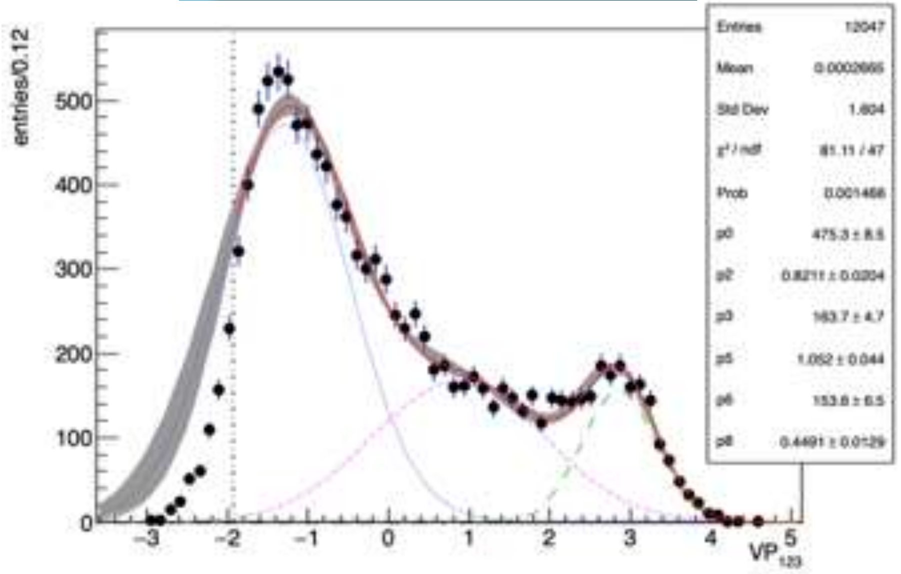
2

N trials	10230

Z TPr	Mean	St. Dev
2	72.25%	4.17%
3	17.98%	4.21%
4	9.77%	0.705%

VP_{123} Fits - Error evaluation

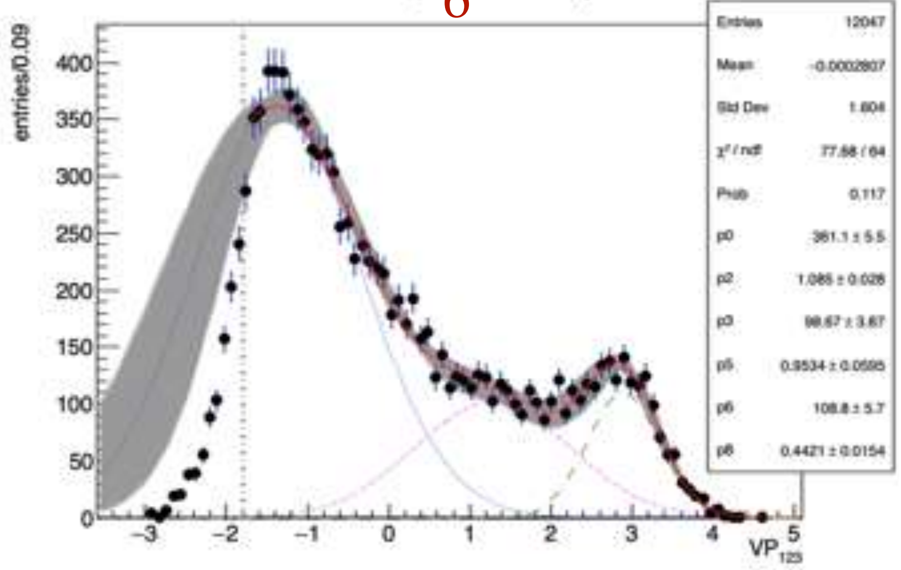
4



N trials	34874

Z TPr	Mean	St. Dev
2	62.92%	3.25%
3	26.68%	3.16%
4	10.41%	0.39%

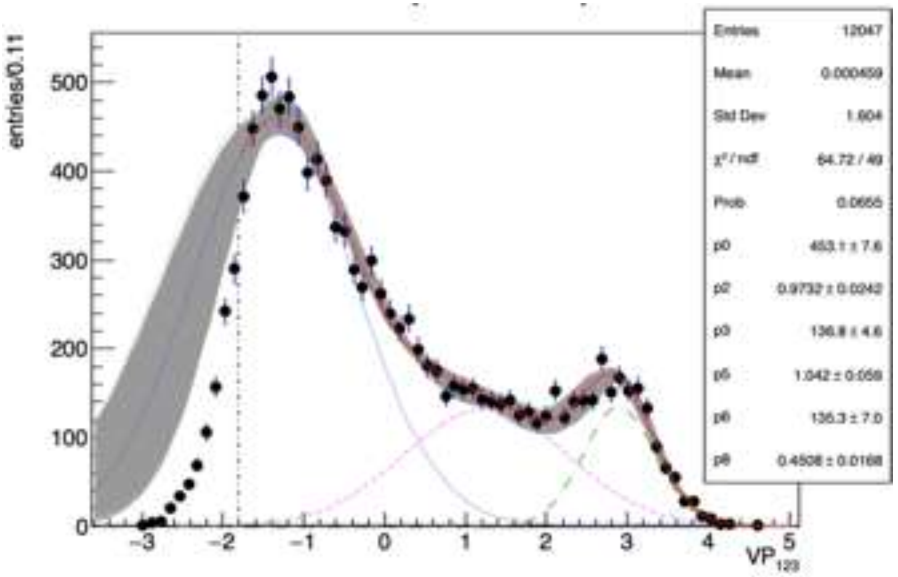
6



N trials	10180

Z TPr	Mean	St. Dev
2	71.43%	4.39%
3	18.91%	4.44%
4	9.66%	0.73%

5



N trials	10453

Z TPr	Mean	St. Dev
2	70.23%	4.74%
3	20.45%	4.73%
4	9.33%	0.77%

Fits - Gaus Par + Systematic ERROR

Tot trks VP_{123}	8772

Fit #	Z=2		Z=3		Z≥4	
	Mean	Dev.St	Mean	Dev.St	Mean	Dev.St
1	51.8%	5.9%	37.5%	5.9%	10.7%	0.49%
2	72.3%	4.2%	18.0%	4.2%	9.8%	0.71%
3	63.5%	4.7%	26.2%	4.7%	10.4%	0.59%
4	62.9%	3.3%	26.7%	3.2%	10.4%	0.39%
5	70.2%	4.7%	20.4%	4.7%	9.3%	0.77%
6	71.4%	4.4%	18.9%	4.4%	9.7%	0.73%

RESULT:

	Z=2			Z=3			Z≥4			TOT
	Mean	Syst	Gaus Par	Mean	Syst	Gaus Par	Mean	Syst	Gaus Par	
# trks	5675	898	154	2214	857	154	872	60	20	8762
%	64.7%	10.2%	1.76%	25.2%	9.8%	1.75%	9.9%	0.7%	0.228%	1

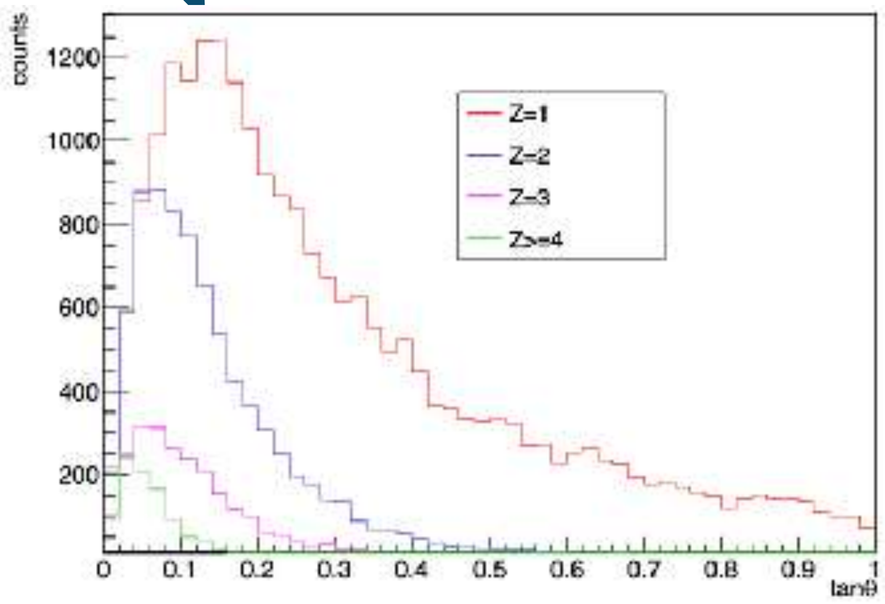
weighted average

(Max-Min)/2

Dev. st. on weighted average

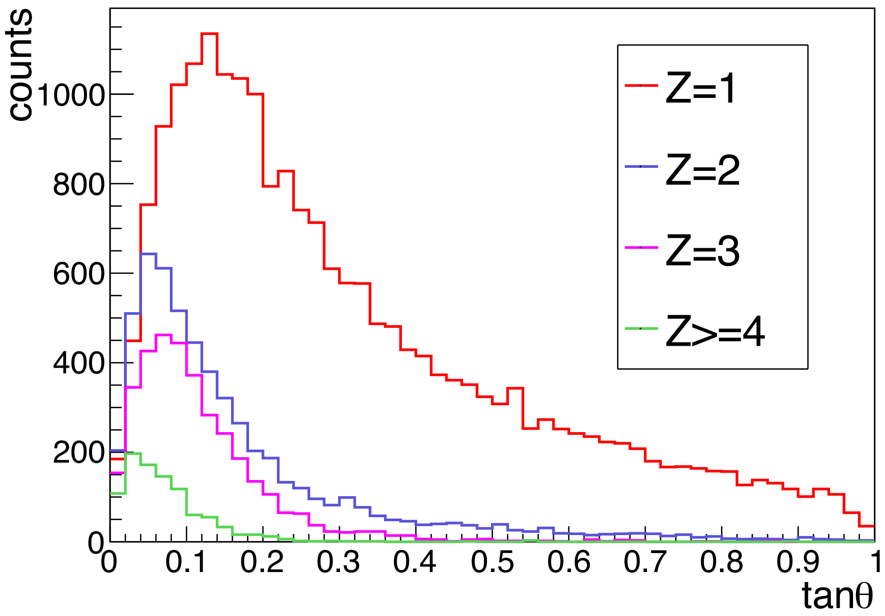
Distributions with Z Flag - Comparison with GSI2

GSI1



Z	Mean	RMS
1	0.31	0.23
2	0.15	0.13
3	0.12	0.10
≥4	0.06	0.04

GSI2



Z	Mean	RMS
1	0.32	0.23
2	0.17	0.17
3	0.11	0.09
≥4	0.08	0.07

GSI1 Results and comparison with GSI2

GSI1

Z	% on total charged			
	Result	Systematic err	Gauss Param err	Statistic err
1	67%	2%	/	1%
2	22%	3%	0%	1%
3	8%	2%	0%	2%
≥4	3%	0%	0%	3%

GSI2

Z	% on total charged			
	Result	Systematic err	Gauss Param err	Statistic err
1	70%	5%	/	1%
2	16%	2%	0%	1%
3	10%	2%	0%	2%
≥4	4%	1%	0%	3%

Conclusions

- Work in progress for the evaluation of reconstruction efficiency in order to provide the first cross section measurement: procedure already prepared
- New faster algorithm to improve vertices reconstruction. Many problems in vertices reconstruction already solved. Visual checks on-going. To do: data control sample

- The paper “Charge identification of fragments with the emulsion spectrometer of the FOOT experiment” has been accepted for publication on Open Physics
- First results for GSI1 charge analysis are in good agreement with GSI2 results: the analysis is robust

THANK YOU!