UPDATE ON THE ANALYSIS OF GSI2 ¹⁶O (200 MEV) ON C AND C₂H₄

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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 \leftarrow 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 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)



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 ($n \le 3$)
- 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	
13182	11350	Number of vertices to which the algorithm is applied
8667	7006	Number of vertices after algorithm
1824	1293	beam tracks found after improvement #6 (slide 10)
1128	769	daughter tracks found after improvement #7 (slide 10)
1895	1426	tracks merged after improvements #1 (slide 7) and #3 (slide 8)
70%	77%	% of tracks belonging to the main MC Event ID
5970	5282	Number of vertices with at least 3 tracks
	GSI1 13182 8667 1824 1128 1895 70% 5970	GSI1GSI21318211350866770061824129311287691895142670%77%59705282

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

Some results on "improved" vertices (DATA)

			PRE
	GSI2 Reco	GSI2 Data	MINARY
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≥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	



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Charge identification paper

Article accepted on Open Physics!

OF LOAD TED

Property Series

Research Article

Open Access

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Abarrar: The COOT (Progressiantion Of Target) experi- of the particles path, in the Desga pash entre and to iners is an international project designed to care and the enhanced holigies, effectiveness of hadran hearts, the financial second out on more remember relevant for a research in terms of the Relative Finlager (Right) second Danger Particle Tampy (CFT), a triangle model in (DDC). The MDC values defined as the same of produces The associated whereas practicity frequency for the involving of the charges providers, done providers, the same fundamental steep toxical taniours. The FOOT deliveror consists of an other, to assessed to an everage value of 7.1 for perform derivative wing for the identification of $Z \ge 3$ imaginarity frames (20). This value is affected by bein given d here and of an emulsion resctoratory for Z = 1 fragments. particle type does, Linear Carryy Transfert and Robal-The first data taking was performed in 2009 at the GSI call parameters file, there true, call evide phase, Companyfacility (Darmand), Germany). In this paper, the charge - tion Seriel (21), and many correct studies highly support. Mentification of fragments induced by examine an on the La conceptionality or alsols to review the statistics on the shared-restor, reducible, a C/R, topot, to an Orygen. BRR place in the defend particle [11, 10, 21] Expedies, too becaused X-20 MeV ye conferenced. The effects discretely physical parameters target begins dation players by misestimate build on an end of the long of a close end date. In the warpy senabley log-cents multitude to contribute to order to colored duce to make many in the normalizer ment the flaw dependion in normal dependencing for en-TRECOME

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1 Introduction

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Taraya) experiment [7, 15] has been proposed to used. more the traget frequencies the conducted by a proton basis in the house taxing to the energy much educat for Herepetito applications (190-200 MeV for protein and 200-400 MAY in Recordson cost: As fragments generated two proton betra have few succentrations magic an inverse. also multipappossible for the strength of a which a primary beam (circhos or Usyger) implays an targets made of ... carbon and by improvanished carbon materials (C₂R₄). Threefairs, the moss-sentian die hydrograph is derived from their is seen all in the

FOOT wanted by two surgistions to yord approximately activity products where a polar and completence so is a soci 10° with respect to the beam axis, for fragments-2 > 5, and an employed spectrometer, to measure light Fragments (2, 5, 5) tay to 70° with respect to the bears.

In this paper, the charge blentification performance the systematy fragments promined by the hitrarchin-16C (200 M/A/A) plurately bound on a Cyling target by the manipule spectrometer is expected.

The northood for the charge identification is bised atas statistical terminate about serioration provides.



Scanning Progress



• 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)



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 ∈ {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

$$\langle \mathbf{VRx} \rangle = \frac{\sum_{NRx} VRx}{NRx}$$

Charge Measurement



- Combining the four $\langle VRx \rangle$ variables we can distinguish the particles' charge:
 - \rightarrow Z \leq 2: sharp cuts on VR0 and VR1
 - \rightarrow Z \geq 2: Principal Components Analysis

Entries

10077

100

80

60

40

20



Cosmic Rays and High Energy Z=1



- Cosmic Rays:
 - line0a: $\langle VR0 \rangle < 1285.71*tan\theta + 5900 \& \langle VR0 \rangle = 0 \& NR1 < 2 \& NR2 < 0 \& NR3 < 0$
 - line0b: $\langle VR0 \rangle < 1892.86*tan\theta + 5900 \& \langle VR0 \rangle != 0 \& NR1 < 2 \& NR2 < 0 \& NR3 < 0$
 - line0c: $\langle VR0 \rangle < 2500*tan\theta + 5900 \& \langle VR0 \rangle != 0 \& NR1 < 2 \& NR2 < 0 \& NR3 < 0$
- <u>High energy Z=1</u>: $\langle VR0 \rangle \ge line0^* \&\&NR1 < 2\&\&NR2 < 2\&\&NR3 < 2$

Z=1 Low energy

VR0 vs VR1 (no cut on VR2 and VR3)





• Low energy Z=1:

- ▶ line1a: $\langle VR0 \rangle \ge 0$ & & $0 < \langle VR1 \rangle \le 4500$ & & NR2 < 2 & & NR3 < 2
- ▶ line1b: $\langle VR0 \rangle \ge 0$ & & $0 < \langle VR1 \rangle \le 4750$ & NR2 < 2 & NR3 < 2
- $\bullet \quad \text{line1c: } \langle \text{VR0} \rangle \ge 0 \&\& 0 < \langle \text{VR1} \rangle \le 5000 \&\& \text{NR2} < 2 \&\& \text{NR3} < 2$
- <u>High energy Z=2</u>: $\langle VR1 \rangle \ge line1 * \& NR2 < 2 \& NR3 < 2$

Error Evaluation for Sharp Cuts

RESULTS

0.8 0.9

tane

0.6

0.5

0.7

							MEA line0b /	AN line1b	ERI (Max-	ROR Min)/2
	line0a / line1a	a		line0c / line1a	a	z	# trks	% on total	# trks	% o tota
Z	# trks	% on total	z	# trks	% on total	Cosmi	07130	80%	645	1 0/
Cosmic	96462	79.3%	Cosmic	97752	80.3%	c Rays	37103	0070	0-10	17
1	23594	19.4%	1	22304	18.3%	Z=1	23048	19%	766	3%
2	1617	1.3%	2	1617	1.3%					
Tot	121673		Tot	121673		Z=2	1486	1%	121	8%
	line0a / line1	c		line0c / line1	C	тот	121673			
Z	# trks	% on total	Z	# trks	% on total	stan El	Cosmic Ray	•		~~ ^{_1}]
Cosmic	96462	79.3%	Cosmic	97752	80.3%	8 3500 E	Pragments	dentified with the cut-to	ased analysis	<u>ر</u> – ا
1	23835	19.6%	1	22545	18.5%	3000	Entries 24534	Entries 97		
2	1376	1.1%	2	1376	1.1%	2500		ىي	J.	
Tot	121673		Tot	121673		1500				

1000

500

0

0.1

0.2

0.3

0.4

Comparison between GSI2 and GSI1





Summary Charge Measurement Z≤2



- <u>Z=0:</u> 0<(VR0)< 3392.86*tanθ+6750 & NR1<2 & NR2<2 & NR3<2
- High energy Z=1: $\langle VR0 \rangle$ $\geq 3392.86* \tan\theta + 6750 \& NR1 < 2 \& NR2 < 2 \& NR3 < 2$
- **10²** <u>Low energy Z=1:</u> $\langle VR0 \rangle \ge 0 \&$ 0< $\langle VR1 \rangle \le 4750 \& NR2 < 2 \& NR3 < 2$
- ¹⁰ <u>High energy Z=2:</u> ⟨VR1⟩>4750 & NR2<2 & NR3<2
 - Z≥2: at least 3 VRx → Principal Components Analysis

Principal Components Analysis (Pca)

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

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

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



VP₁₂₃ Fits - Error evaluation



N tri	als	13285
Z TPr	Mean	St. Dev
2	51.78%	5.85%
3	37.52%	5.90%
4	10.70%	0.49%



2 N tria	als	10230
Z TPr	Mean	St. Dev
2	72.25%	4.17%
3	17.98%	4.21%
4	9.77%	0.705%

0



N tria	als	13162
Z TPr	Mean	St. Dev
2	63.46%	4.68%
3	26.19%	4.68%
4	10.35%	0.59%

VP₁₂₃ Fits - Error evaluation



N tria	als	34874
Z TPr	Mean	St. Dev
2	62.92%	3.25%
3	26.68%	3.16%
4	10.41%	0.39%



) N tria	als	10453
Z TPr	Mean	St. Dev
2	70.23%	4.74%
3	20.45%	4.73%
4	9.33%	0.77%



N tria	als	10180
Z TPr	Mean	St. Dev
2	71.43%	4.39%
3	18.91%	4.44%
4	9.66%	0.73%

Fits - Gaus Par + Systematic ERROR

Tot trks VP ₁₂₃	3	3772					
	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:



Distributions with Z Flag - Comparison with GSI2





GSI1 Results and comparison with **GSI2**

GSI1

GSI2

Z	% on total charged					% on total charged			
	Result	Systematic err	Gauss Param err	Statistic err	Z	Result	Systematic err	Gauss Param err	Statistic err
1	67%	2%	/	1%	1	70%	5%	/	1%
2	22%	3%	0%	1%	2	16%	2%	0%	1%
3	8%	2%	0%	2%	3	10%	2%	0%	2%
≥4	3%	0%	0%	3%	≥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

