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

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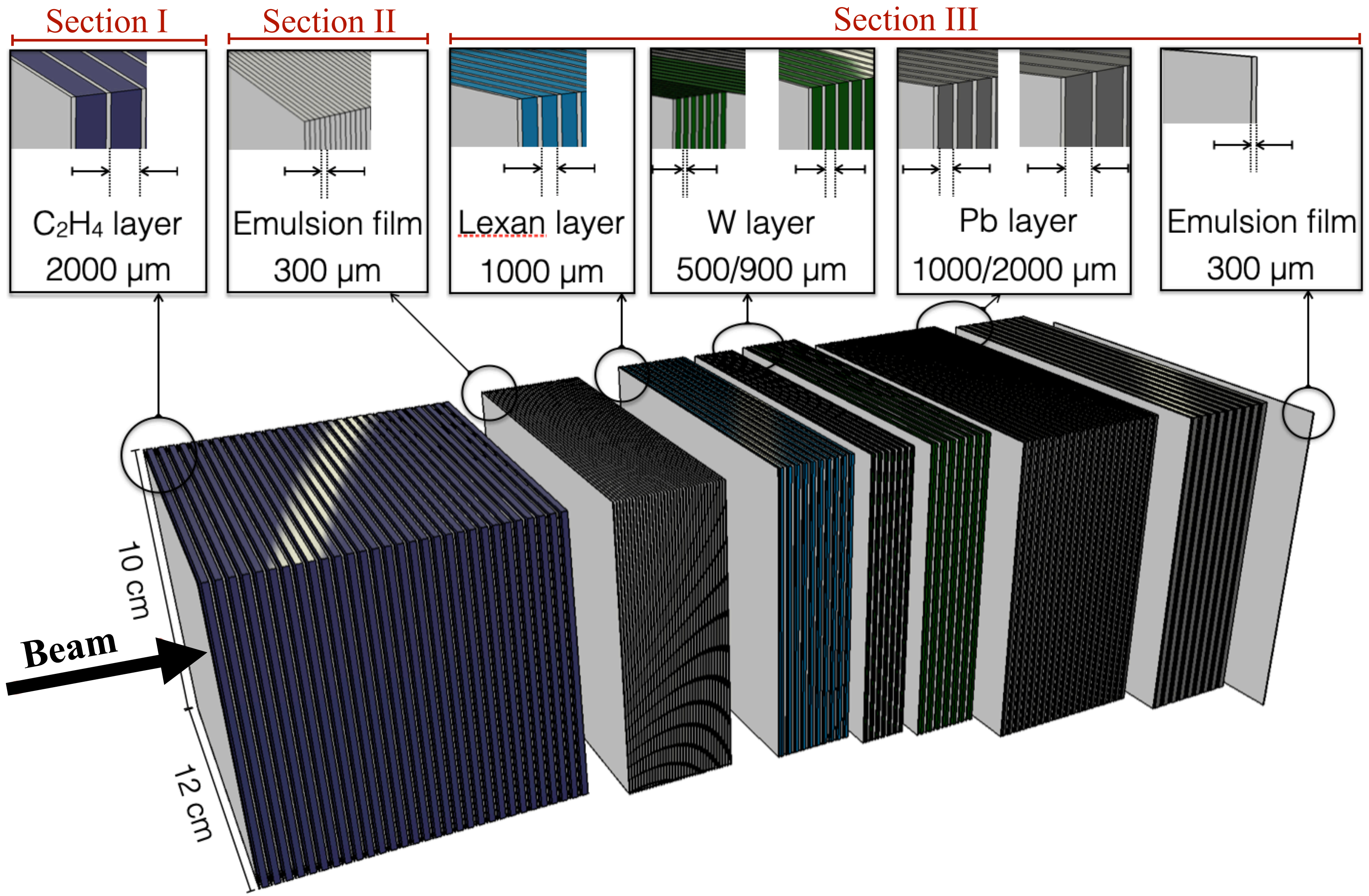
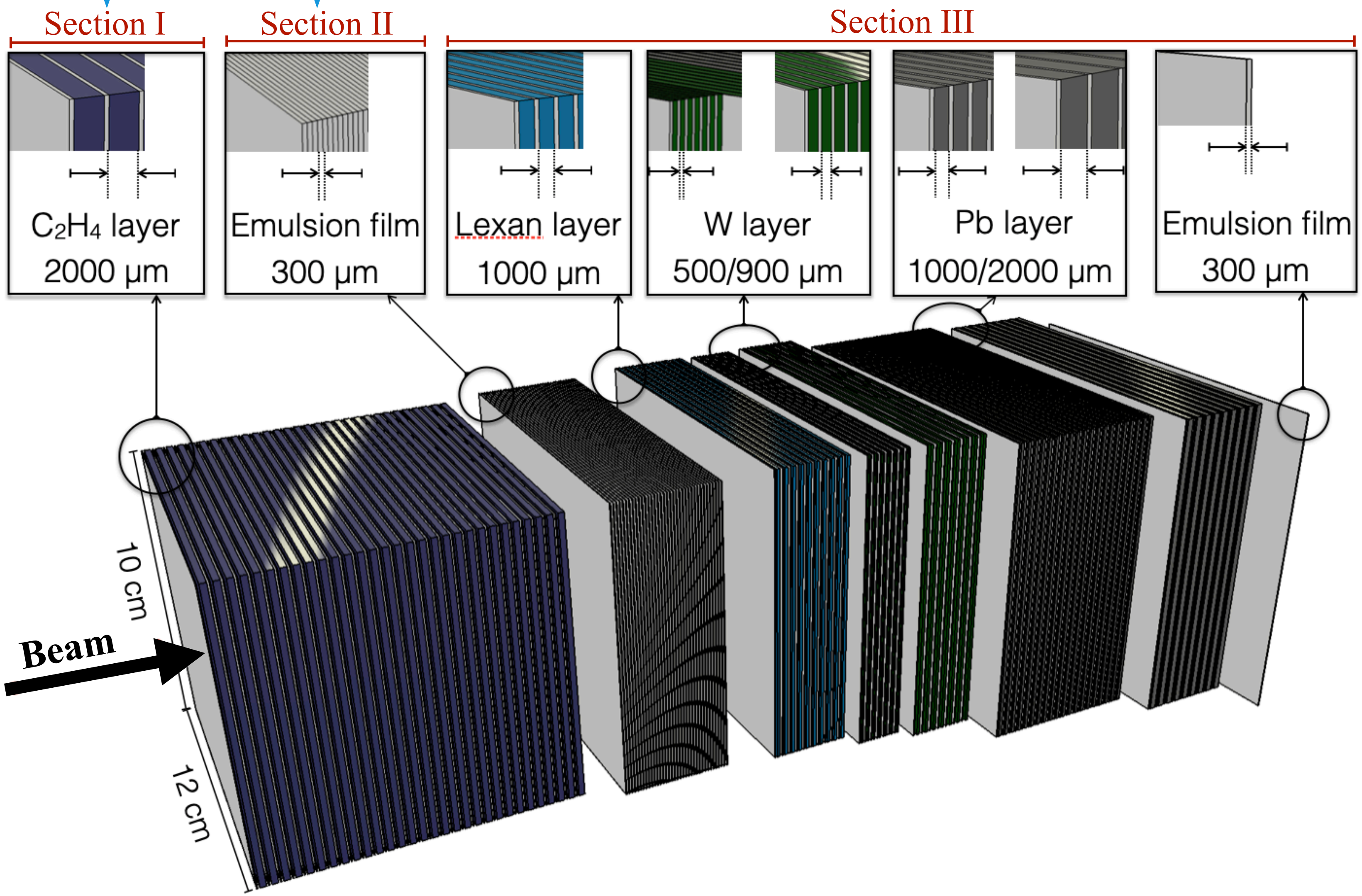
10/12/2020, General FOOT Meeting - ZOOM

Detector Structure



Detector Structure

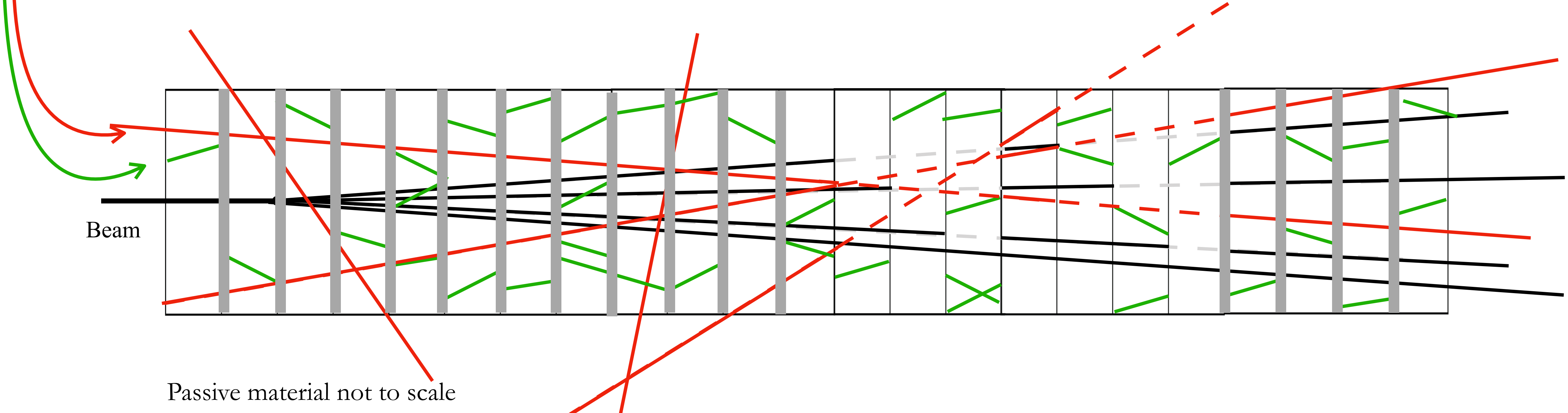


Background in Monte Carlo Simulation

- 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).

- When the brick is assembled it integrates cosmic rays that are then reconstructed as long tracks. These could mimic a vertex or be associated to a true vertex if they're reconstructed as more than one track



Passive material not to scale

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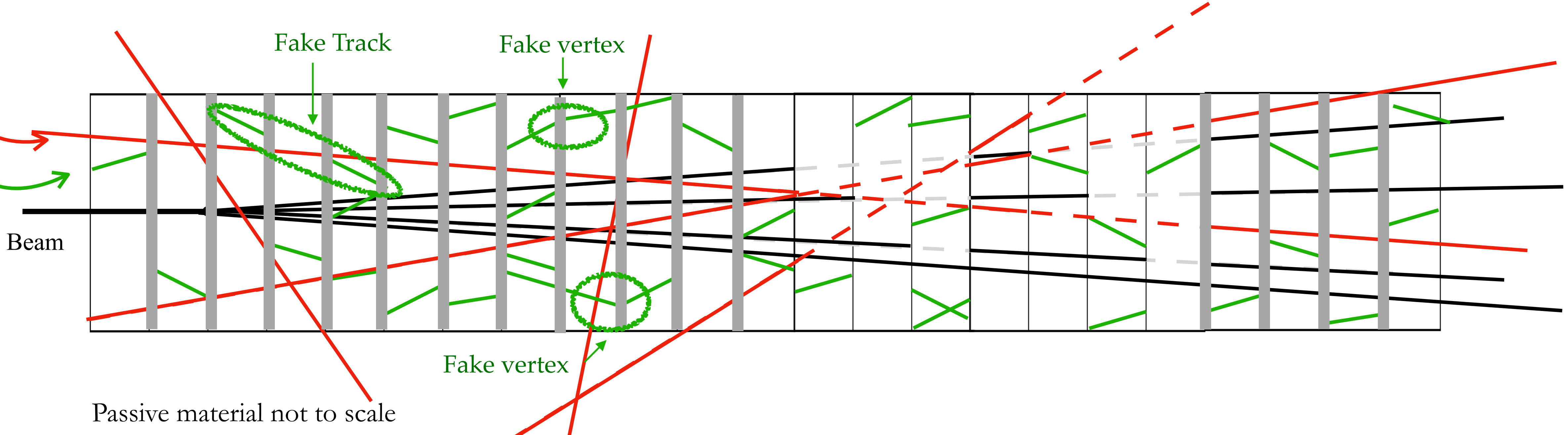
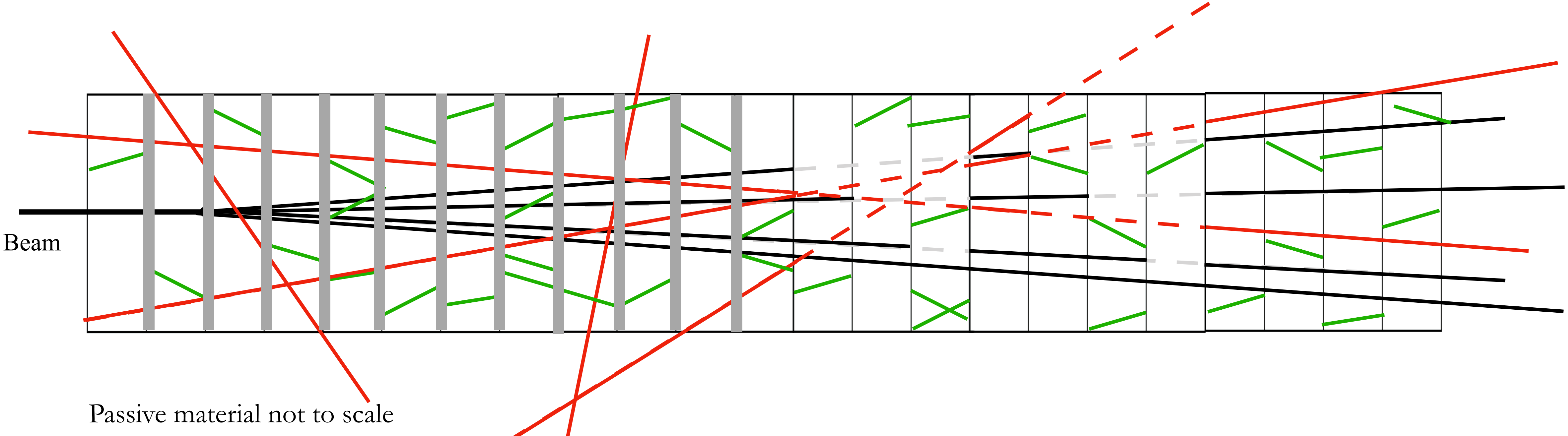


Background in Monte Carlo Simulation

- These two sources of background were not present in Monte Carlo simulation

- Segments integrated when the brick was not assembled have been added



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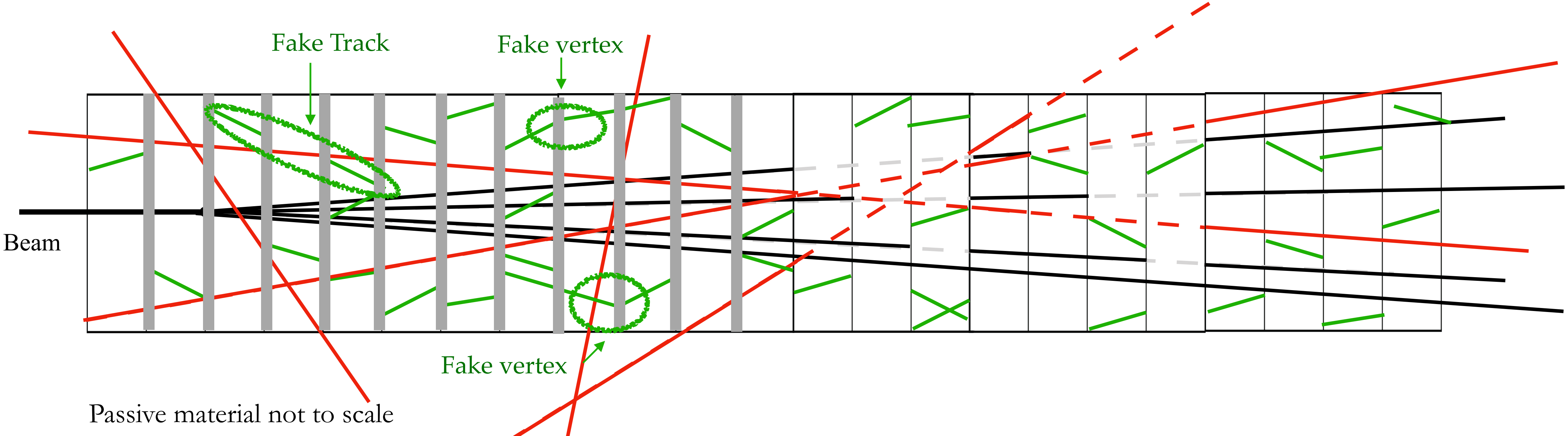
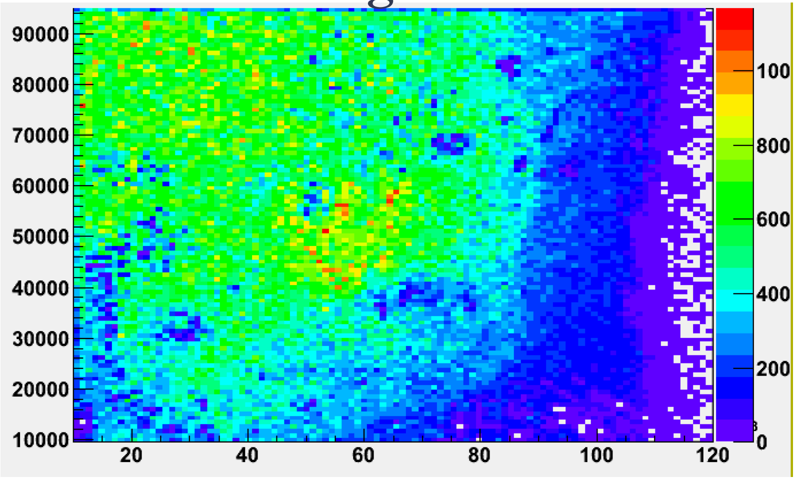


Combinatorial Background added to MC - Example

- Background segments were taken from data, in a region with no signal

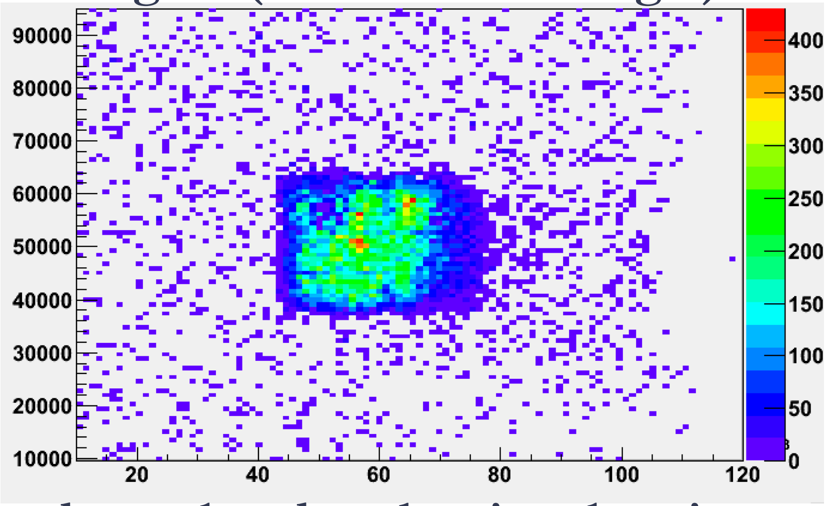
All segments



DATA

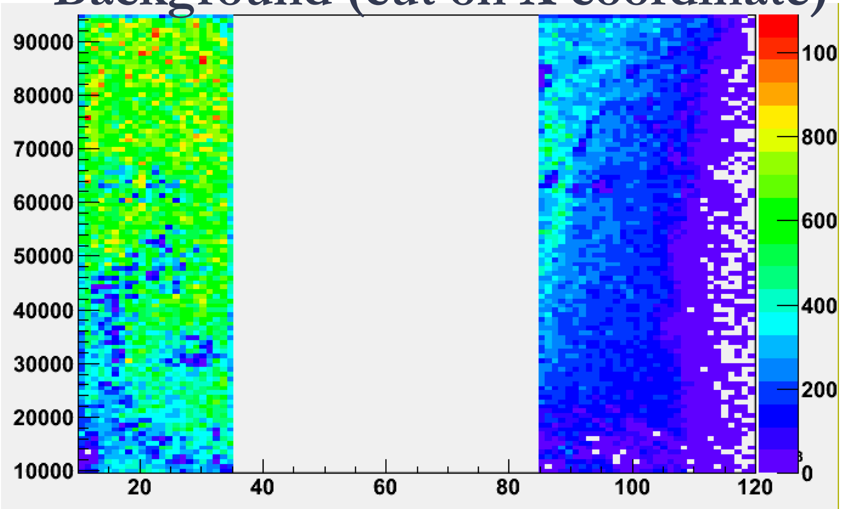
3803509 entries

Signal (cut on track's angle)



DATA
105744 entries

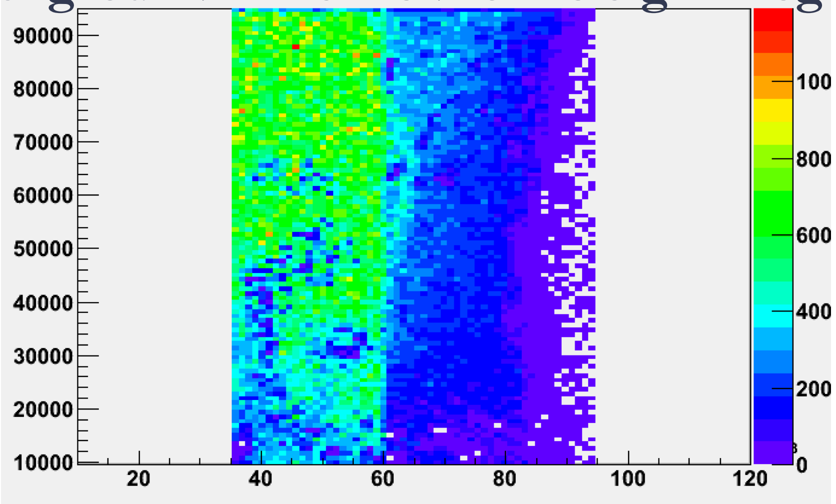
Background (cut on X coordinate)



DATA

1604247 entries

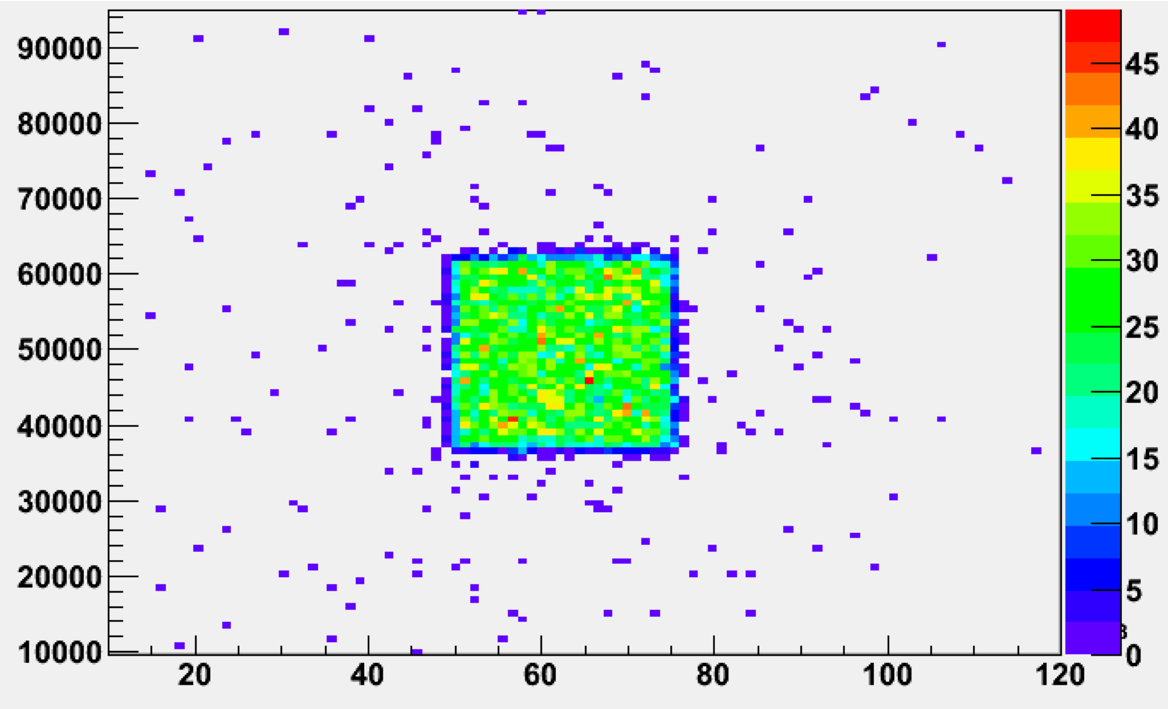
Background translated to the signal region



Combinatorial Background added to MC - Example

- and added to MC simulation, after being shifted

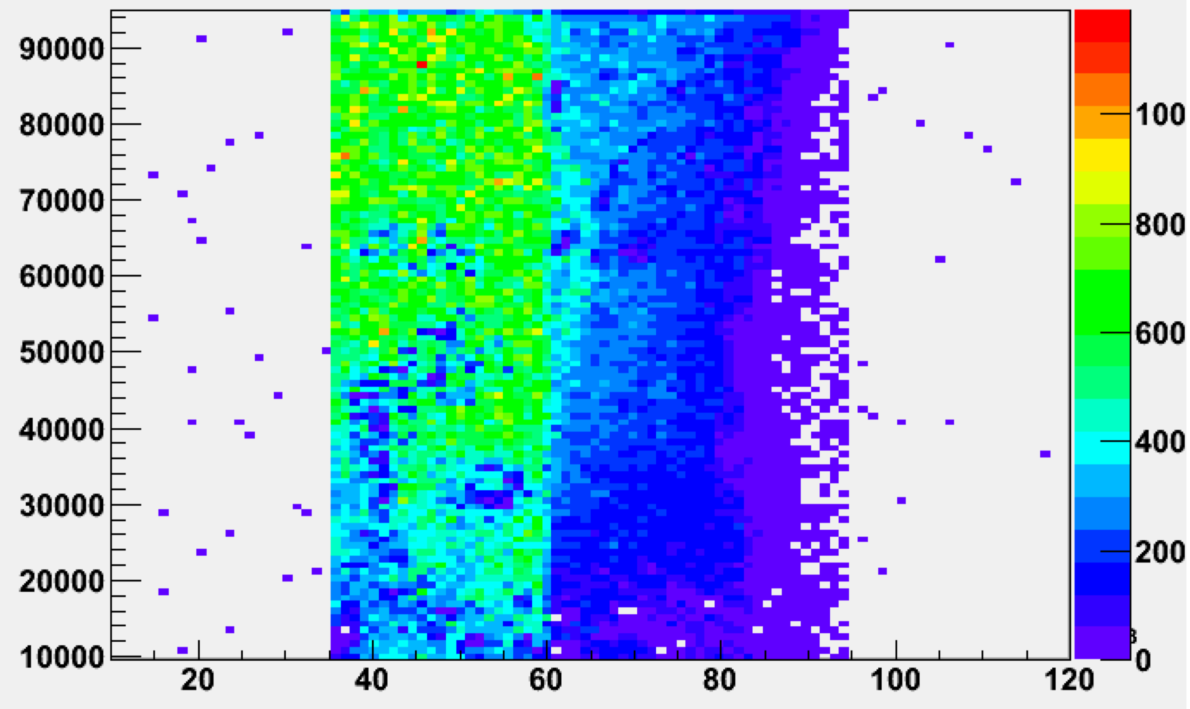
All segments



18746 entries

MC

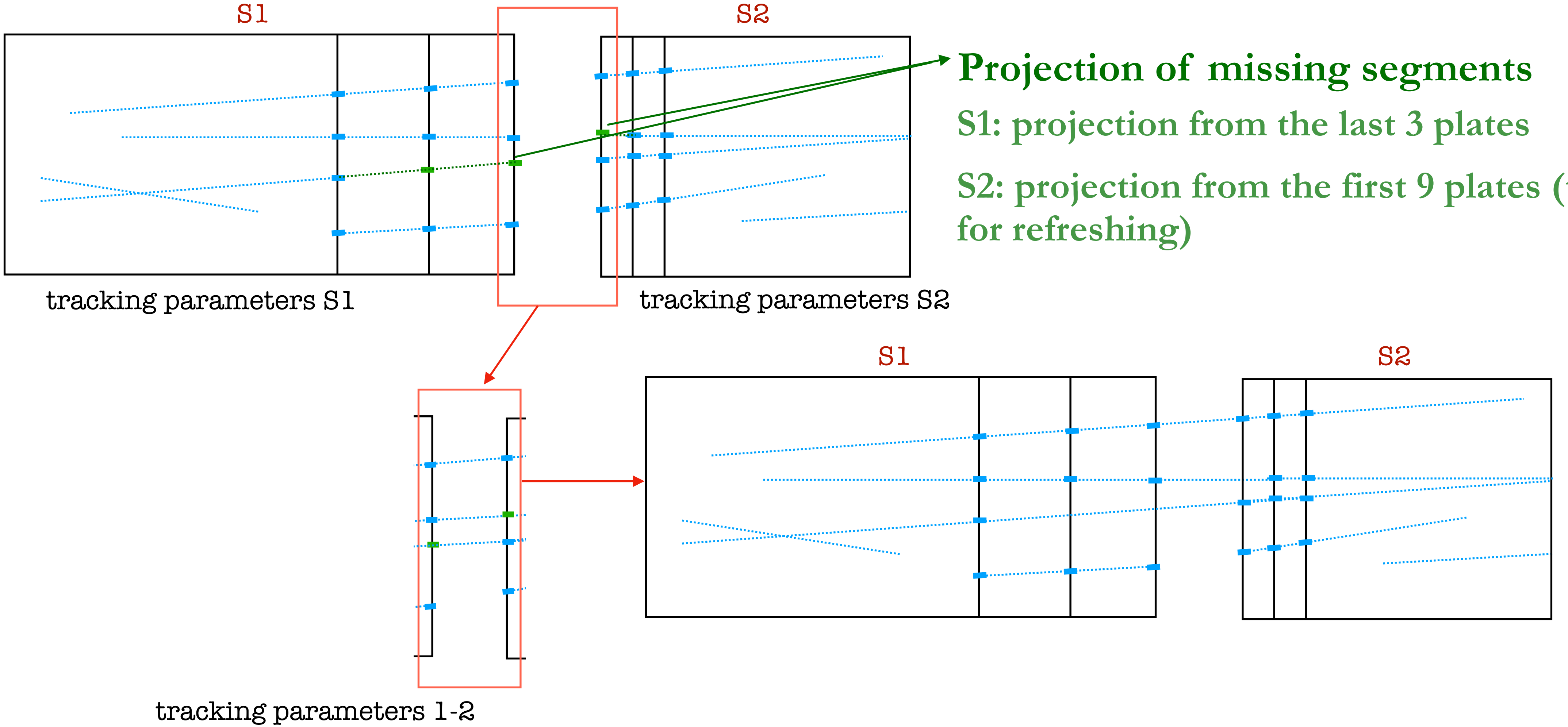
Signal (cut on track's angle)



1622993 entries

Tracking

- Track reconstruction performed separately for each section, with appropriate parameters
- Algorithm developed to merge tracks reconstructed in two sections



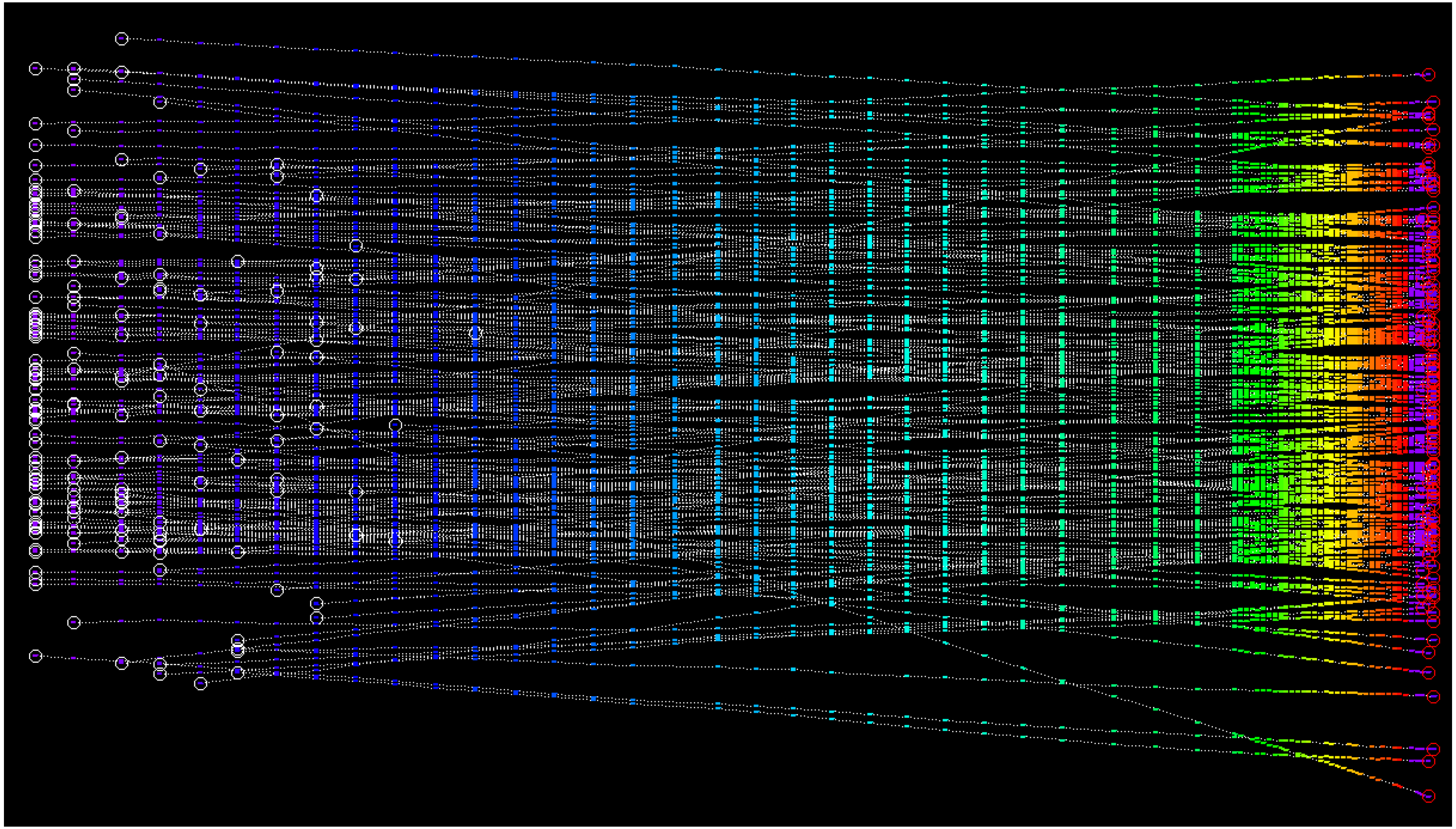
Projection of missing segments

S1: projection from the last 3 plates

S2: projection from the first 9 plates (to account for refreshing)

Tracking

(Cut: nseg>50)

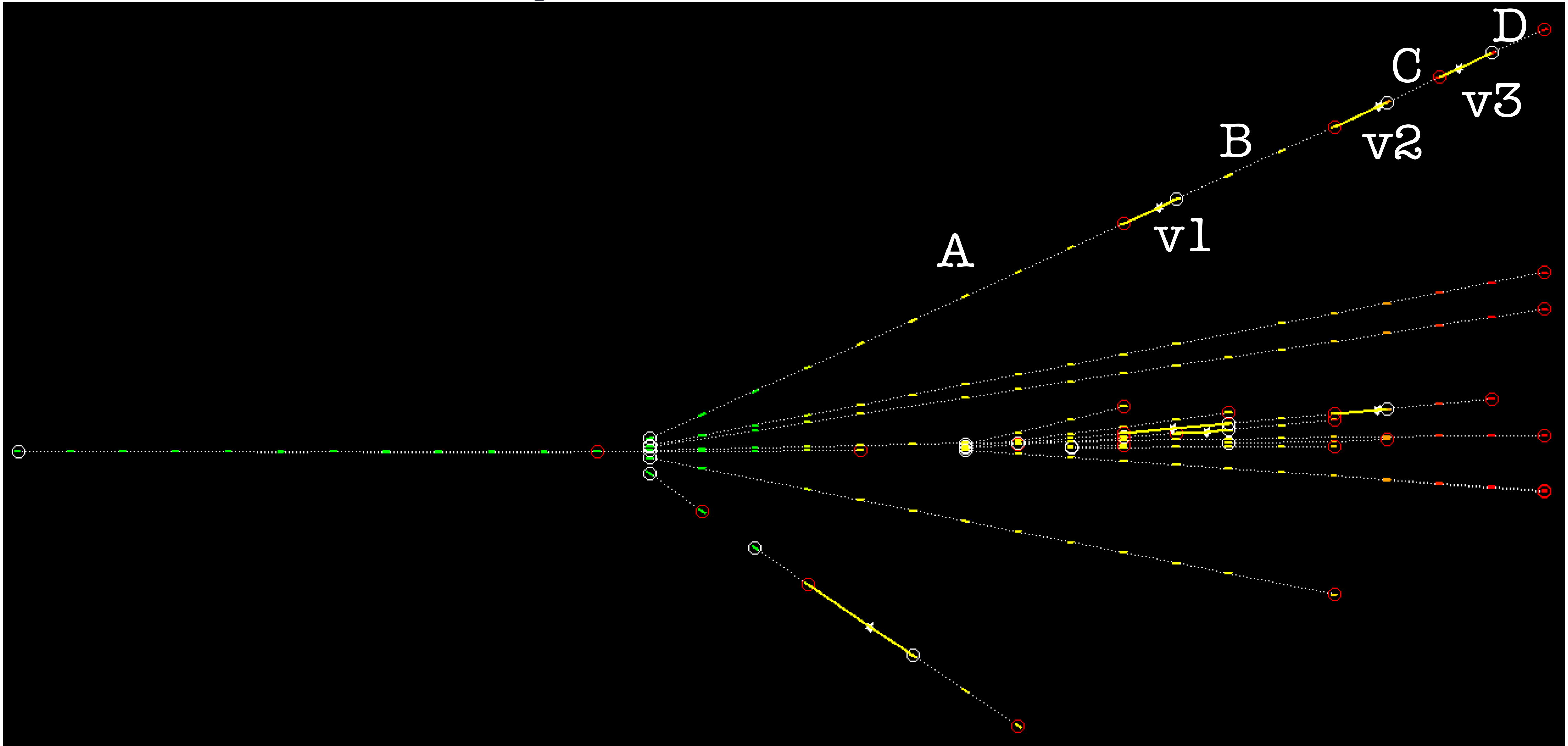


S1 (~70.5 mm)

S2 (~12.6 mm)

Tracking

- 2-prongs back-to-back vertices, formed due to more stringent tracking parameters, are reattached in a unique track



Vertices Selection: MC and DATA Samples

	MC	Data
Entries	11350	12412
n≥3	4660	3748
n=2	6690	8664
vtx good n≥3	3912	
vtx good n=2	1472	
tot good	5384	

(MC and DATA normalised to beam particles)

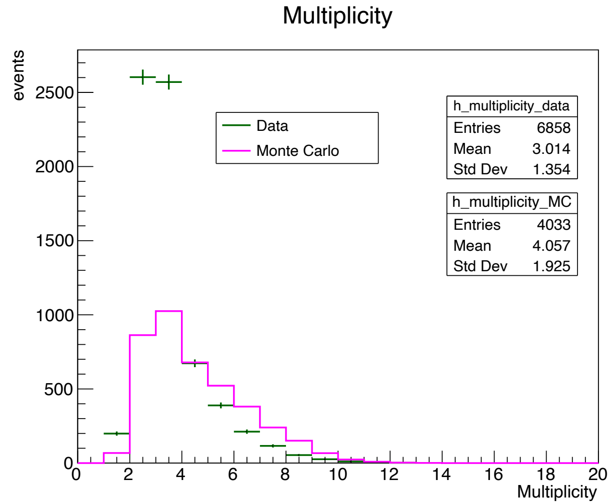
Expected ~6300

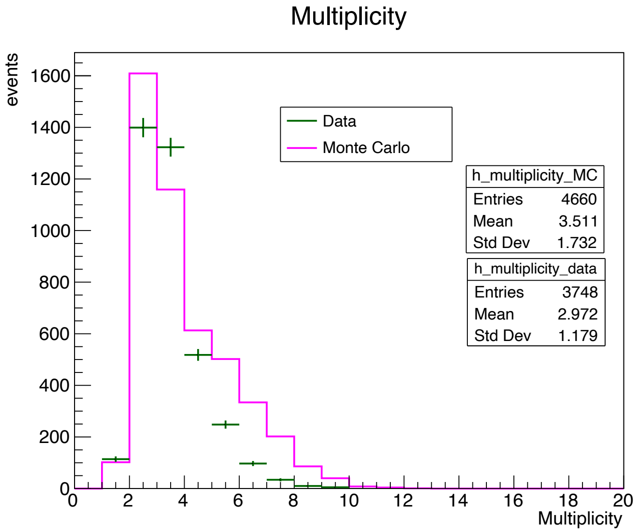
- Many vertices reconstructed: not all of them are true ones
- A MC vertex is considered good if it has at least 2 tracks belonging the same MC event
- Need to improve vertices reconstruction: good results already obtained and reported in the next slides

Data and MC Comparison

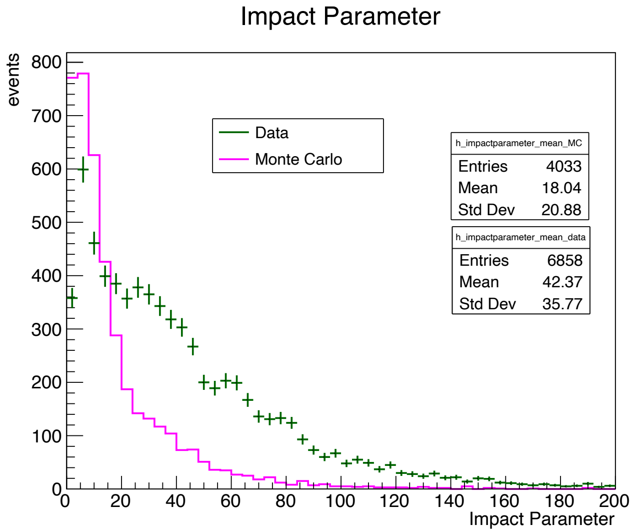
- MC now describes Data much better than before

Before

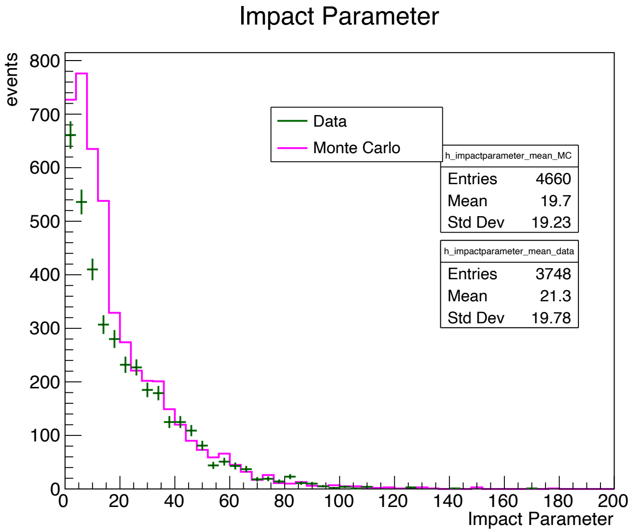




Now

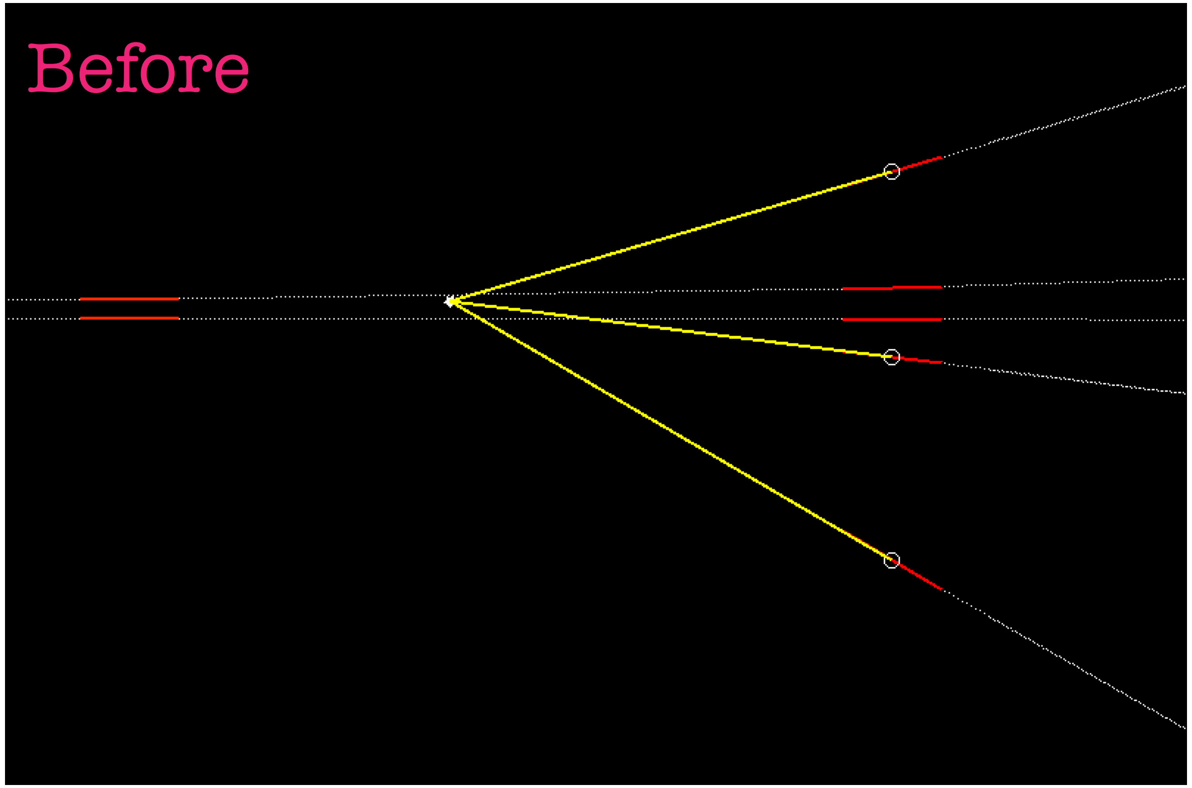


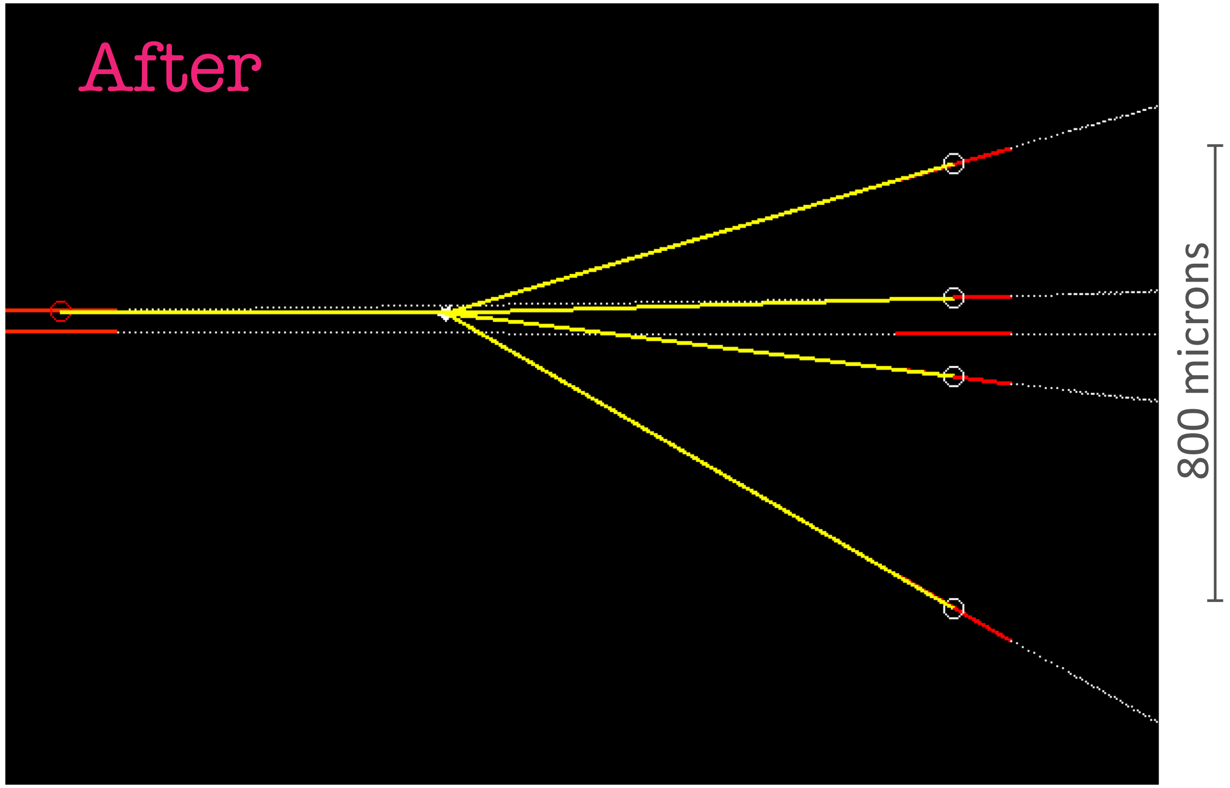
MC and DATA normalised to beam particles



Vertexing - improvements I

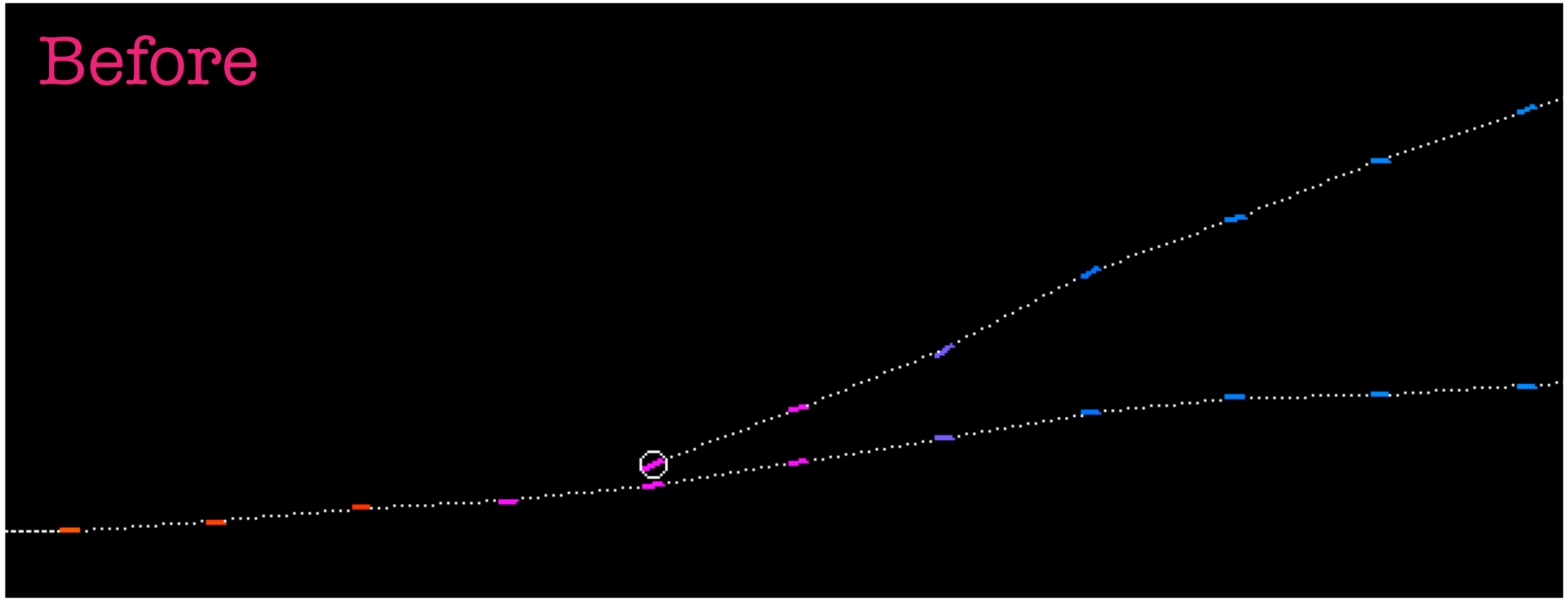
- Improvements to restore some vertices topologies:
  Oxygen passing through a vertex, because reconstructed as unique track with one of the daughters

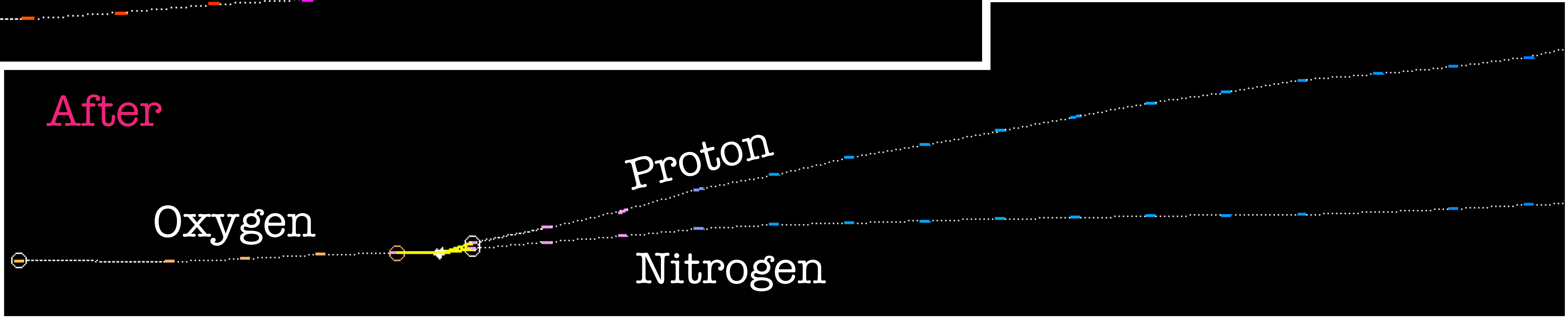




Vertexing - improvements II

- Improvements to restore some vertices topologies: O→N+p



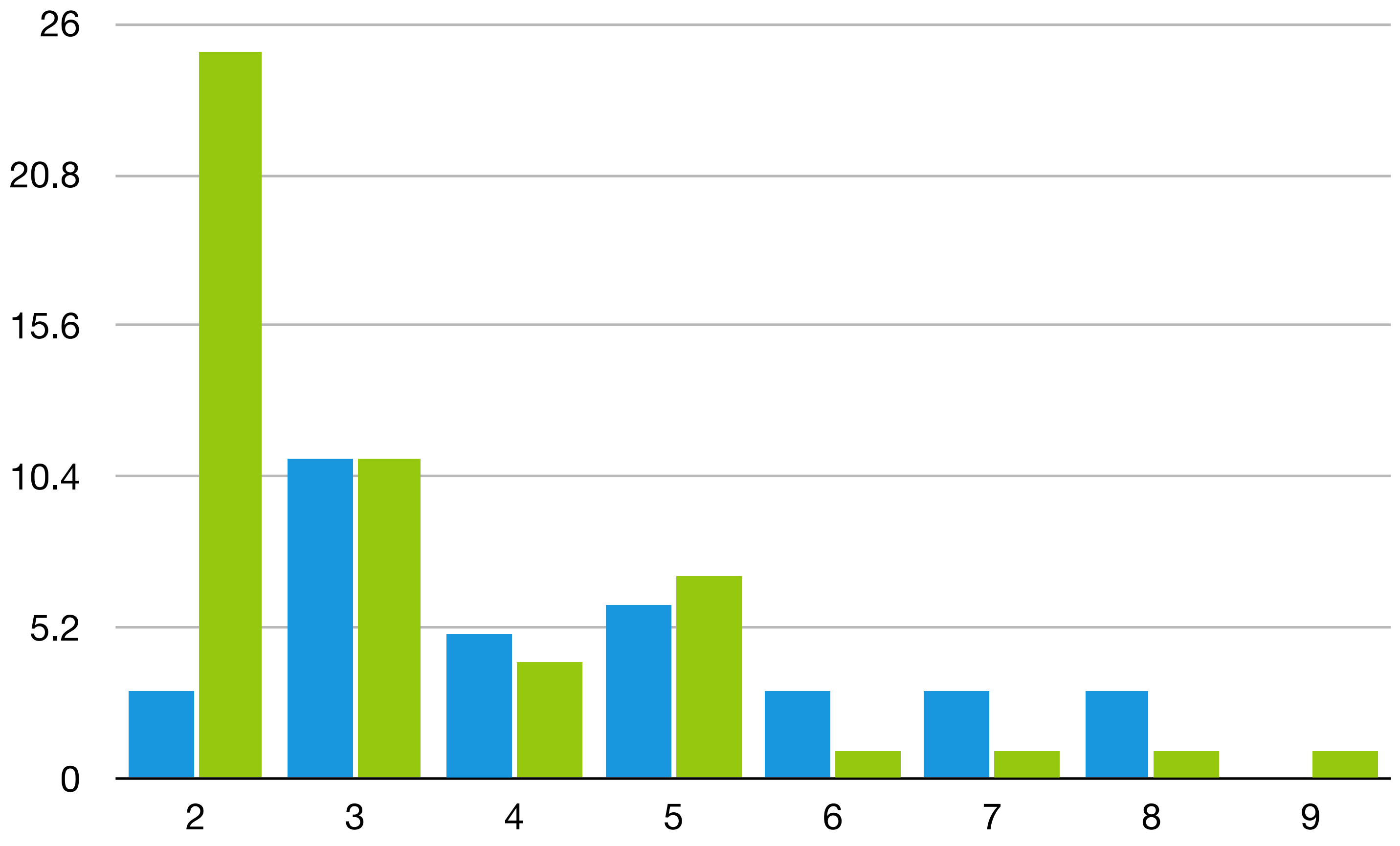


Vertexing: 2 mm^2 test MC

- Test with a small volume Monte Carlo only: comparison between Truth vs **standard** vertices reconstruction (no improvements)

	True	Reco
entries	119	
Oxy at BP (*)	88	55
Tot vtx	34	51
Tot vtx n>2	31	26

Multiplicity	True	Reco
2	3	25
3	11	11
4	5	4
5	6	7
6	3	1
7	3	1
8	3	1
9	0	1



(*) Oxy at BP = npl>23 & firstplate<4

Vertexing: 2 mm^2 test MC

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5	6	7
6	3	1
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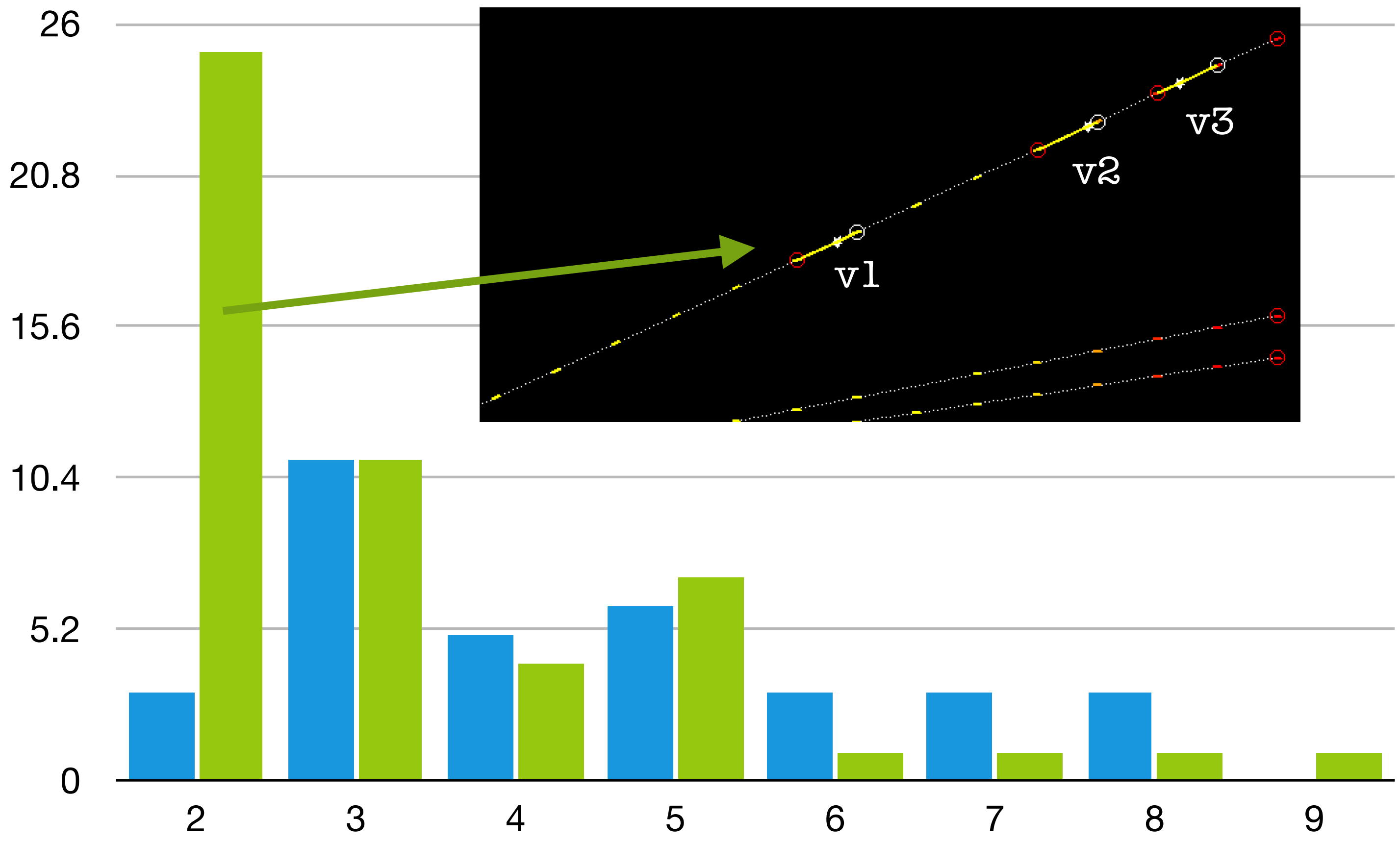
8	3	1
9	0	1



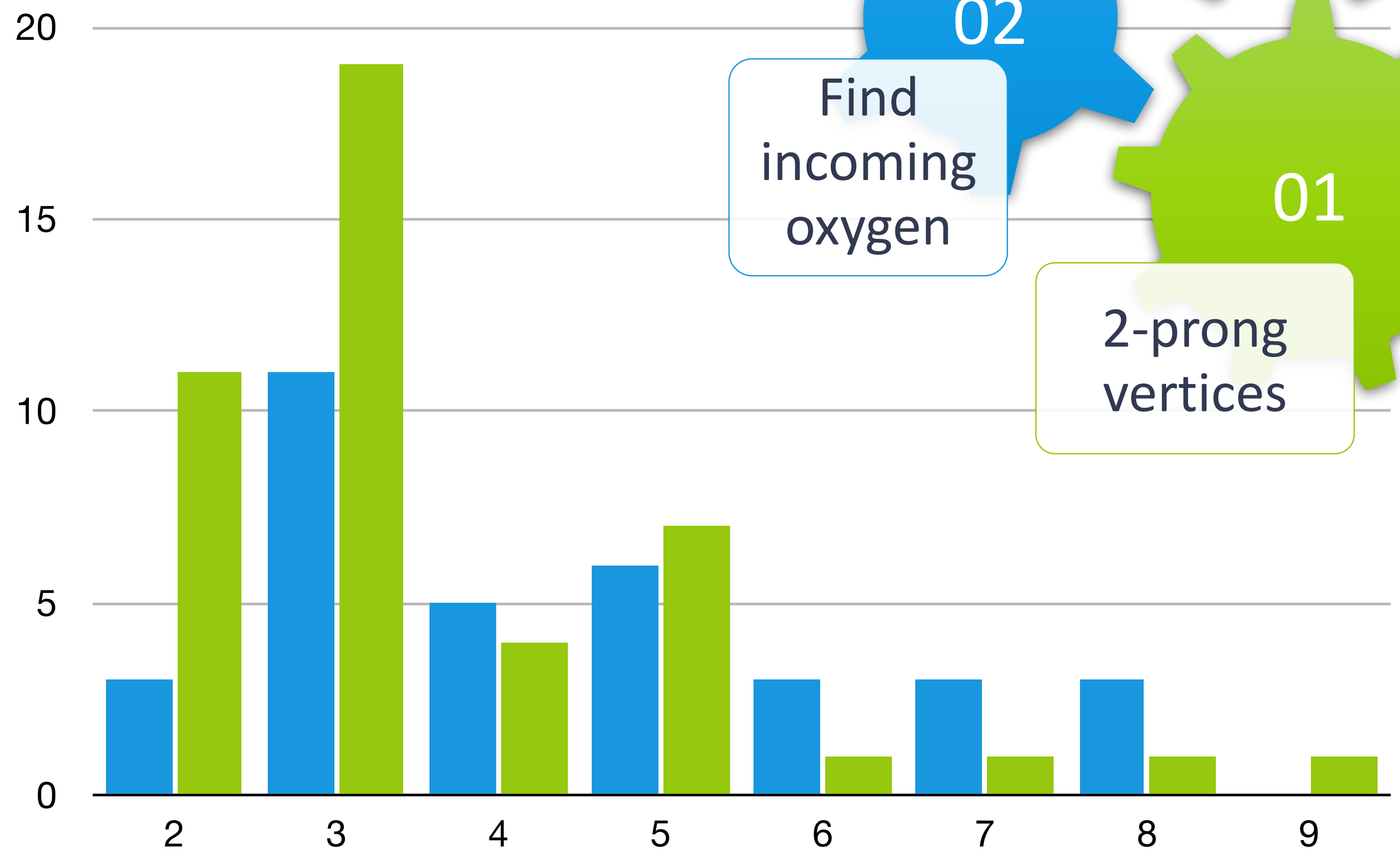
(*) Oxy at BP = npl>23 & firstplate<4

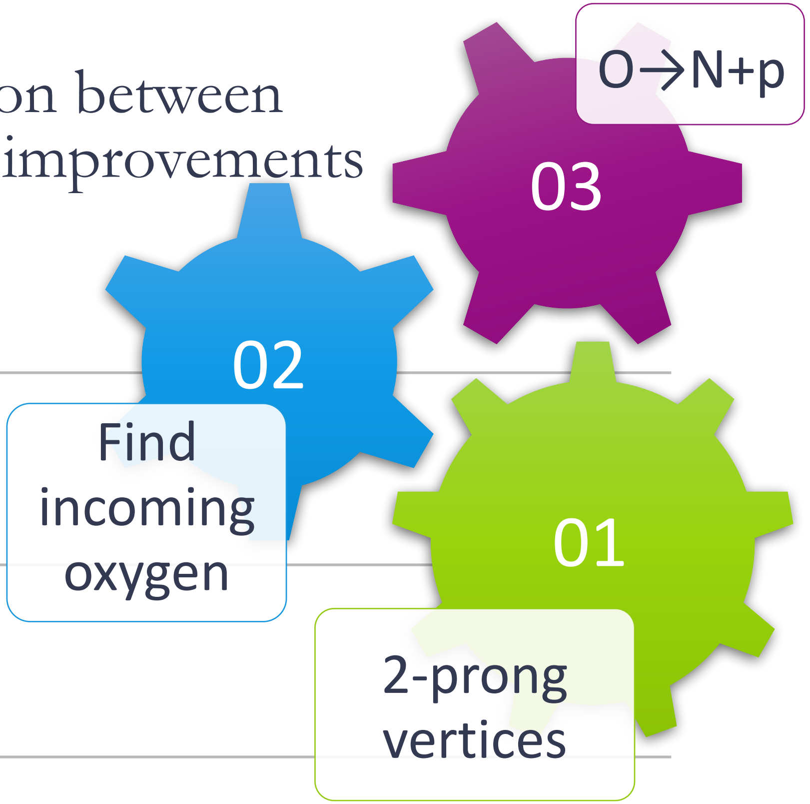
Vertexing: 2 mm² test MC

- Test with a small volume Monte Carlo only: comparison between Truth vs vertices reconstruction after new algorithms improvements

	True	Reco
Tot vtx	34	45
Tot vtx n>2	31	34

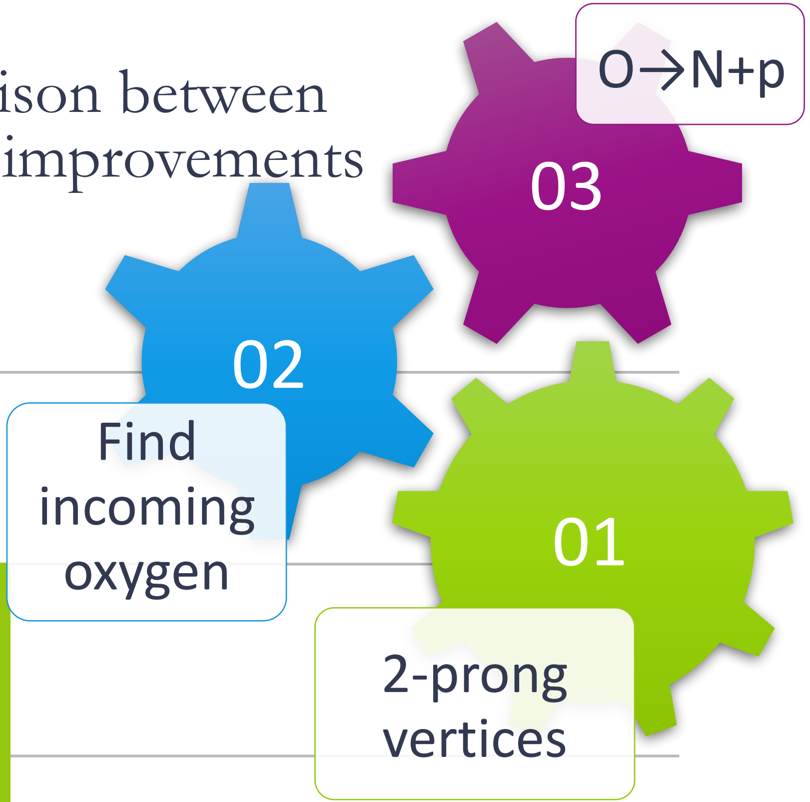
Multiplicity	True	Reco
2	3	11
3	11	19
4	5	4
5	6	7
6	3	1
7	3	1
8	3	1
9	0	1





Vertexing: 2 mm^2 test MC + Bkg

- Test with a small volume Monte Carlo + bkg: comparison between Truth vs vertices reconstruction after new algorithms improvements



	True	Reco
Tot vtx	34	179
Tot vtx n>2	31	27

Multiplicity	True	Reco
2	3	152
3	11	8
4	5	7
5	6	9
6	3	0
7	3	1
8	3	2

Vertices Selection (MC): new results

	Before	Now	
Entries	11350	9918	
n≥3	4660	5848	
n=2	6690	4070	
vtx good n≥3	3912	4926	+21%
vtx good n=2	1472	644	–56%
tot good	5384	5570	

- We are about to reach the number of expected vertices (~6300)
- Nest step: Boosted Decision Tree (BDT) method to classify good and fake vertices

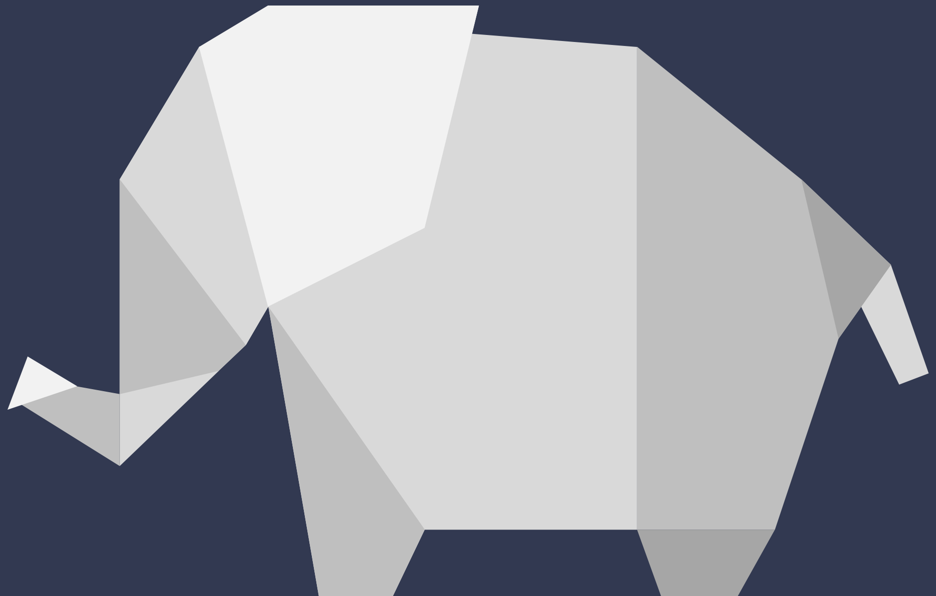
Ref: https://root.cern/doc/v614/classTMVA_1_1MethodBDT.html

Conclusions

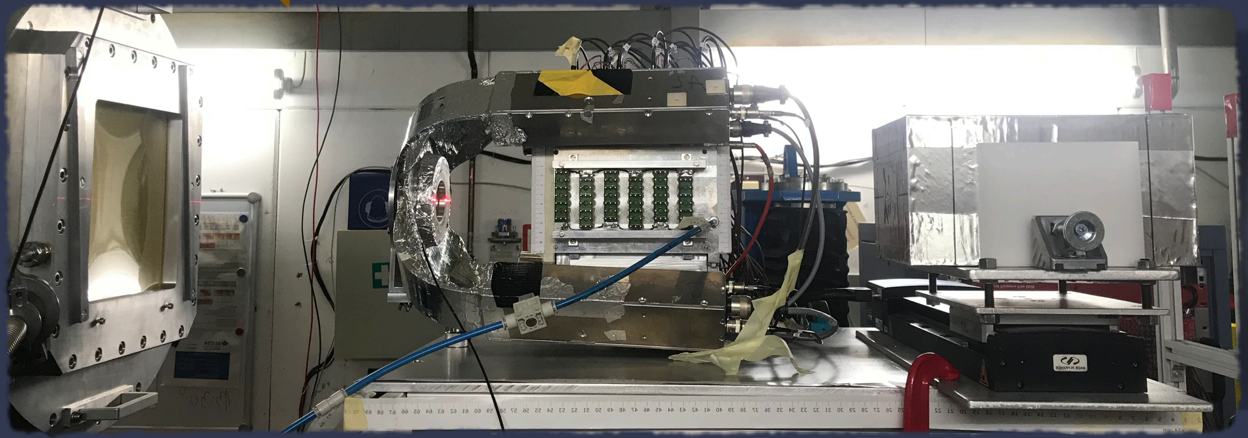
- Combinatorial background added to MC simulation
- Several improvements in tracking and vertexing algorithms:
  - Merge of different sections
  - Reconstruction of topologies where the Oxygen is attached to one of its daughters:
    - tracks passing through a vertex
    - $O \rightarrow N + p$
- Next step: BDT Analysis to classify good and bad vertices
- Still room for improvements!

2020

Report

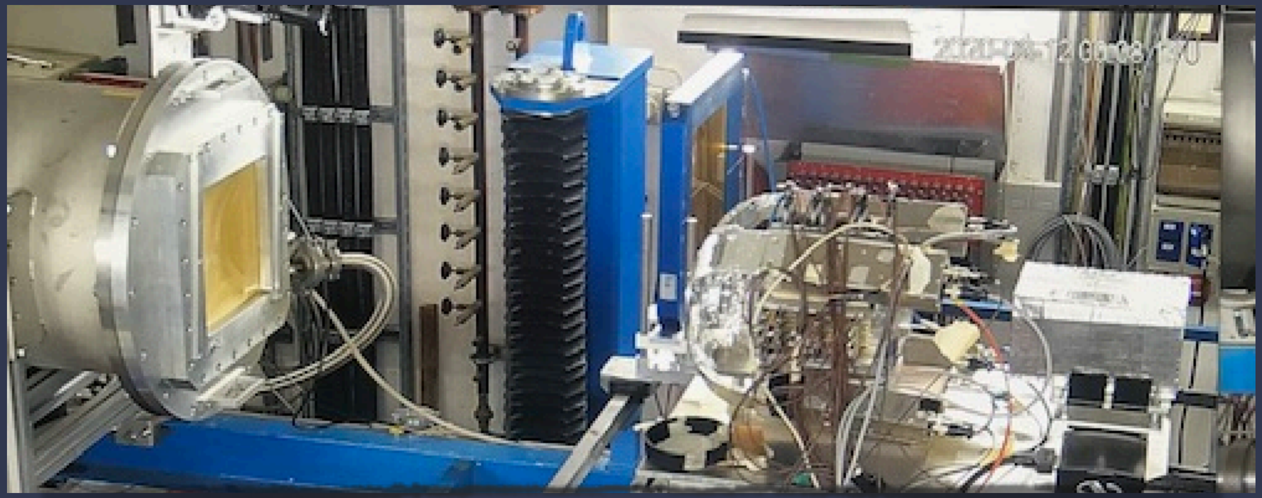


FOOT: Emulsion spectrometer data taking



GSI (run March 2019)

- Scanning completed (520 emulsion films)
- Charge identification on GSI2 (^{16}O@200 MeV/n, C_2H_4 target) completed
- On going analysis



GSI (run February 2020)

- ^{12}C (700@MeV/n)
- 2 ECC exposed (C and C_2H_4 target)
- 72 emulsion films thermally treated
- 328 emulsion films chemically developed
- 80% Scanning completed

Charge identification: analysis completed!

- Article submitted on December 3 on Open Physics

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Research Article Open Access

G. Galati*, A. Alexandrov, B. Alpat, G. Ambrosi, S. Argirò, R. Arteche Diaz, N. Bartosik, G. Battistoni, N. Belcari, E. Bellinzona, S. Biondi, M. G. Bisogni, G. Bruni, P. Carra, P. Cerello, E. Ciarrocchi, A. Clozza, S. Colombi, A. Del Guerra, M. De Simoni, A. Di Crescenzo, B. Di Ruzza, M. Donetti, Y. Dong, M. Durante, R. Faccini, V. Ferrero, E. Fiandrini, C. Finck, E. Fiorina, M. Fischetti, M. Francesconi, M. Franchini, G. Franciosini, L. Galli, V. Gentile, G. Giraudo, R. Hetzel, E. Iarocci, M. Ionica, K. Kanxheri, A. C. Kraan, V. Lante, C. La Tessa, M. Laurenza, A. Lauria, E. Lopez Torres, M. Marafini, C. Massimi, I. Mattei, A. Mengarelli, A. Moggi, M. C. Montesi, M. C. Morone, M. Morrocchi, S. Muraro, F. Murtas, A. Pastore, N. Pastrone, V. Patera, F. Pennazio, P. Placidi, M. Pullia, F. Raffaelli, L. Ramello, R. Ridolfi, V. Rosso, C. Sanelli, A. Sarti, G. Sartorelli, O. Sato, S. Savazzi, L. Scavarda, A. Schiavi, C. Schuy, E. Scifoni, A. Sciubba, A. Sécher, M. Selvi, L. Servoli, G. Silvestre, M. Sitta, R. Spighi, E. Spiriti, G. Sportelli, A. Stahl, V. Tioukov, S. Tomassini, F. Tommasino, M. Toppi, G. Traini, S. M. Valle, M. Vanstalle, M. Villa, U. Weber, R. Zarrella, A. Zoccoli, and G. De Lellis

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

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DOI: DOI

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Abstract: The FOOT (FragmentatiOn Of Target) experiment is an international project designed to carry out the fragmentation cross section measurements relevant for Charged Particle Therapy (CPT), a technique based on the use of charged particle beams for the treatment of deep-seated tumours. The FOOT detector consists of an electronic setup for the identification of $Z \geq 3$ fragments and of an emulsion spectrometer for $Z \leq 3$ fragments. The first data taking was performed in 2019 at the GSI facility (Darmstadt, Germany). In this paper, the charge identification of fragments induced by exposing an emulsion detector, embedding a C_2H_4 target, to an Oxygen ion beam of 200 MeV/n is discussed. The charge identification is based on controlled fading of nuclear emulsions in order to extend their dynamic range in the ionization response

Keywords: Particle therapy, nuclear emulsion, fragmentation

PACS: 29.40.Rg, 42.62.Be

1 Introduction

Charged Particles Therapy (CPT) is an established therapy for cancer treatment. The advantages of CPT are due to the energy release occurring mainly at the end of the particles path, in the Bragg peak region, and to the enhanced biological effectiveness of hadron beams, measured in terms of the Relative Biological Effectiveness (RBE). The RBE value, defined as the ratio of photons to charged particles dose producing the same biological effect, is assessed to an average value of 1.1 for proton beams [20]. This value is affected by both physical (i.e. particle type, dose, Linear Energy Transfer) and biological parameters (i.e. tissue type, cell cycle phase, Oxygenation level) [21], and many recent studies highly support a comprehensive analysis to reduce uncertainties on the RBE value for the clinical practice [11, 19, 21]. Regarding physical parameters, target fragmentation plays a key role as low energy secondary fragments contribute to increment the dose deposition in normal tissues along the entrance channel and in the region surrounding the tumor. Hence, the re-assessment of the proton RBE value due to secondary fragmentation is an important topic [21]. The complexity of dedicated experiments makes this milestone challenging, and in fact very few and limited experimental data are available in literature regarding target fragmentation, and none of them fully describes secondary fragments induced by a proton beam. The fragmentation of carbon ions (400 MeV/n) in a polycarbonate target was studied in 2011 to determine the charge-changing cross-sections by exploiting the nuclear emulsion technology [10].

In this framework, the FOOT (FragmentatiOn Of Target) experiment [7, 15] has been proposed to measure the target fragmentation induced by a proton beam in the human tissues in the energy range relevant for therapeutic applications (150 − 250 MeV for protons and 200−400 MeV/n for carbon ions). As fragments generated by a proton beam have few micrometers range, an inverse kinematic approach has been adopted in which a primary beam (carbon or Oxygen) impinge on targets made of carbon and hydrogen-enriched carbon materials (C_2H_4). Therefore, the cross-section on hydrogen is derived from their linear combination.

FOOT is based by two complementary setups: a magnetic spectrometer, covering a polar angle acceptance up to about 10° with respect to the beam axis, for fragments $Z \geq 3$, and an emulsion spectrometer, to measure light fragments ($Z \leq 3$) up to 70° with respect to the beam axis.

In this paper, the charge identification performance of the secondary fragments generated by the interaction of ^{16}O (200 MeV/n) primary beam on a C_2H_4 target by the emulsion spectrometer is reported.

The method for the charge identification is based on an established technique already performed in previous

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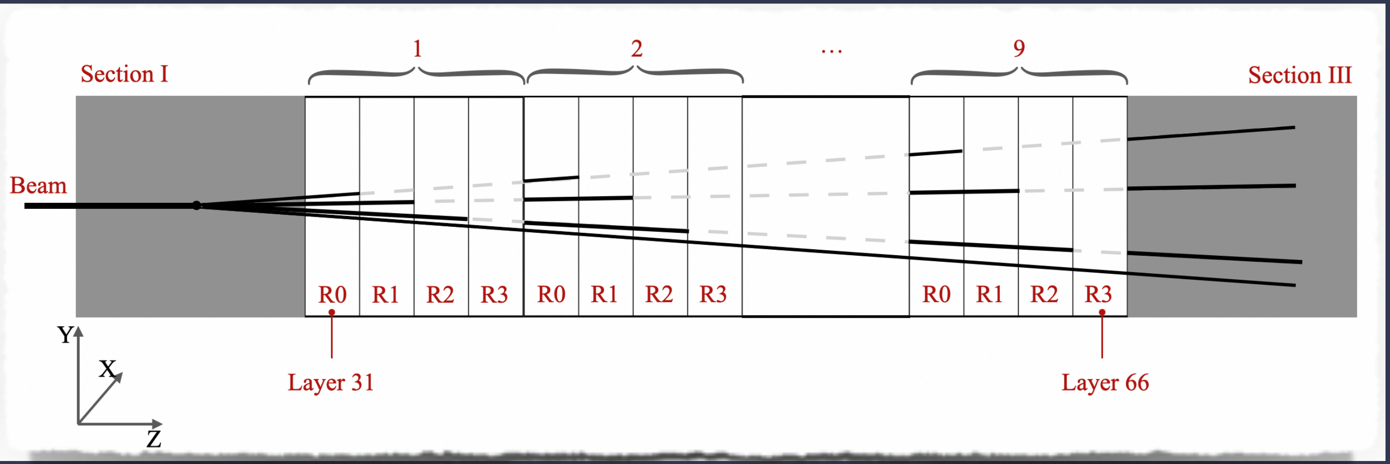
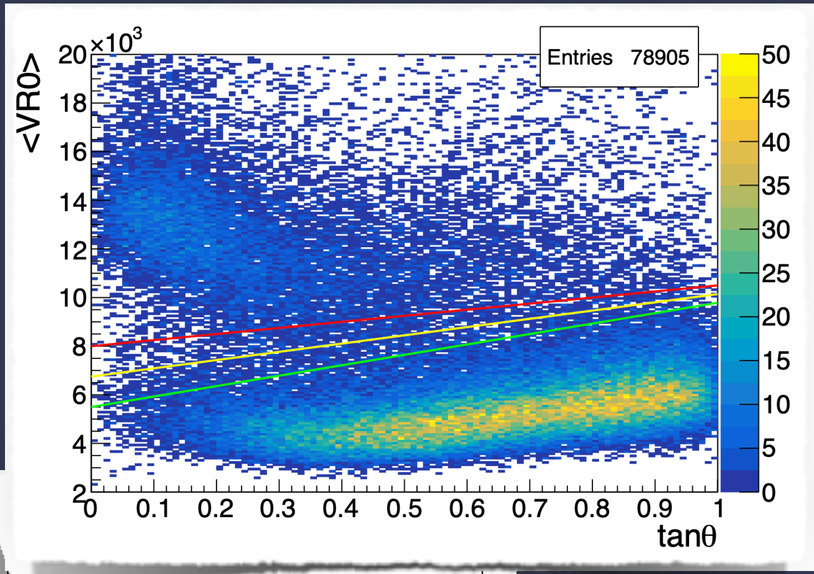
A. Alexandrov, A. Di Crescenzo, V. Gentile, A. Iuliano, A. Lauria, M. C. Montesi, V. Tioukov, G. De Lellis: INFN Section of Napoli, Napoli, Italy

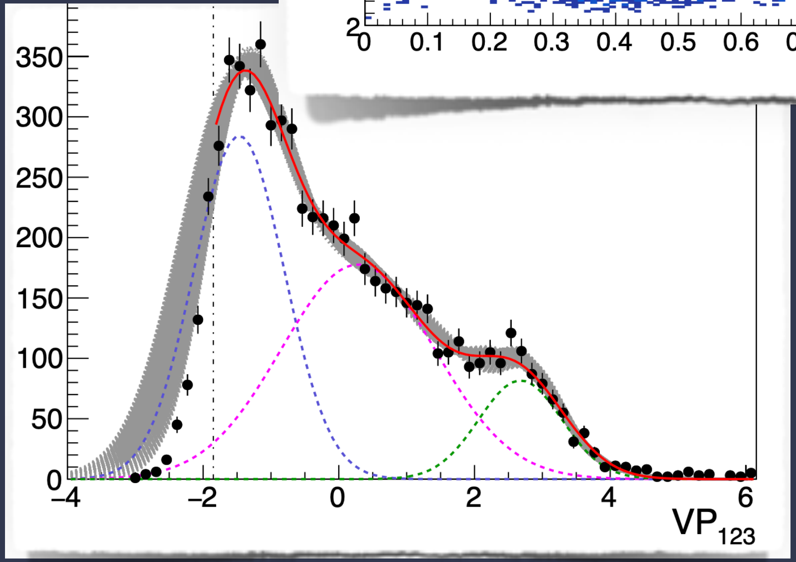
Charge identification: analysis completed!

- Thermal treatments inducing controlled fading of nuclear emulsion films were applied to Section II of the emulsion spectrometer in order to distinguish the charge of fragment



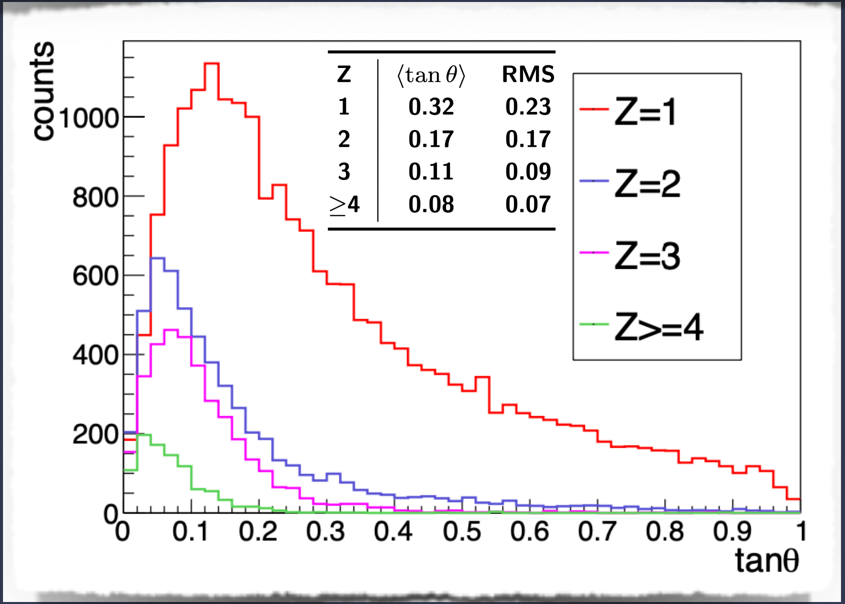


- Fragments charge was measured using two complementary methods:
  - **Cut-based analysis**: Cosmic Rays, Z=1, Z= 2 (high energy)
  - **Principal Component Analysis**: Z=2 (low energy), Z=3, Z≥4



Charge identification: analysis completed!

Z	CB	PCA	Total	%	Syst. Err.	Stat. Err.
	Fragments classification					
1	21199	/	21199	70%	5%	0.7%
2	1438	3506	4943	16%	2%	1.4%
3	/	2915	2915	10%	2%	1.9%
≥4	/	1108	1108	4%	1%	3.0%
Total	22637	7529	30166			



- Charge assigned for 98.3% of reconstructed tracks
- The mean of tanθ distributions decreases with increasing Z, as expected

THANK YOU!

Merry Christmas!