Study of Charged Particle Multiplicity Distributions in High Energy Neutrino-Lead Interactions in the OPERA Detector

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METU-OPERA

International Workshop on Nuclear Emulsions for Neutrino Studies and WIMP Search

25-28 October 2016

Italy

Motivation

-In past charged particle multiplicities were studied in many experiment with different particle beams.

-Different phenomenological and the theoretical models can be tested and it can be used in tunning interaction models in MC event generators.

-The average multiplicities for charged particles, dispersion in the multiplicity of charged particles and KNO Scaling have been studied in different kinematical regions.

Charged-particle multiplicities in charged-current neutrino– and anti-neutrino–nucleus interactions,(CHORUS Col.)Eur. Phys. J. C 51, 775–785 (2007)

Timeline

November 2015 → Data

First Results → " Multiplicity Distributions of OPERA Experiment", International Symposium on EcoTopia Science 2015, November 27-29, 2015, Nagoya University

Results (Multiplicity+ dispersion +KNO) → "MULTIPLICITY DISTRIBUTIONS IN CHARGE - CURRENT NEUTRINO INTERACTIONS" OPERA Collaboration Meeting - Nagoya -March 30-April 1, 2016

Results (Multiplicity+ dispersion+KNO) → "Multiplicity Distributions in Charge Current Neutrino Interactions" OPERA PC Meeting - Nagoya -May 12-2016

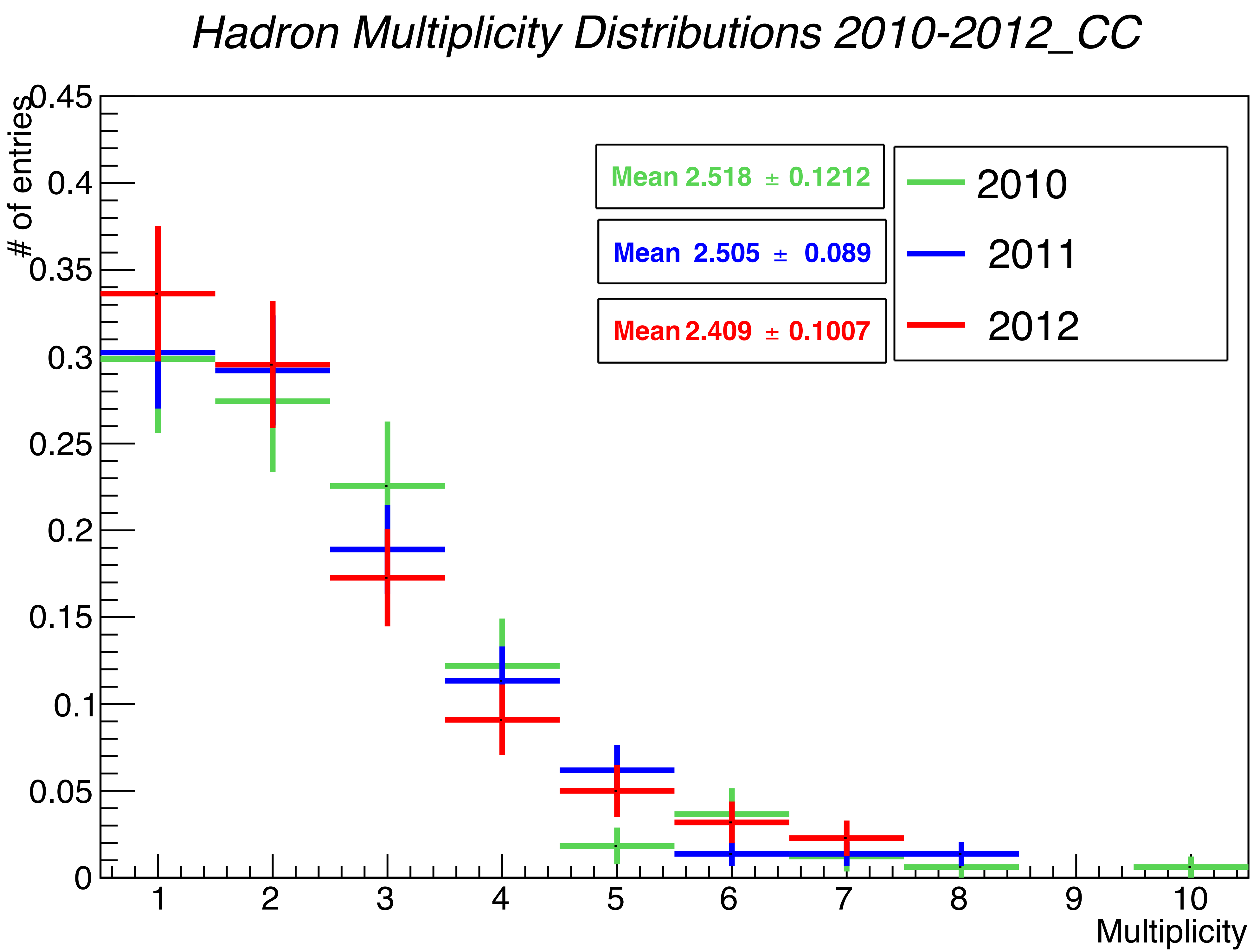
Results (Multiplicity+ dispersion+KNO + *Efficiency study+internal note*) → International Workshop on Nuclear Emulsions for Neutrino Studies and WIMP Search October 2016

Data Sets and Selection

Thank you so much Japan Group

Data sets	*Japan-> Japan DB*
Run	2010-2012
Data	Particle ID(shower/grey/black/ep) flag included
Event Status	DECAYSEARCHED
Event selection	Muon-ID=1 or Tracklength>19
Muon P	<=15 GeV/c^2
Multiplicity	hadron tracks at primary

Hadron Track Multiplicity Distributions



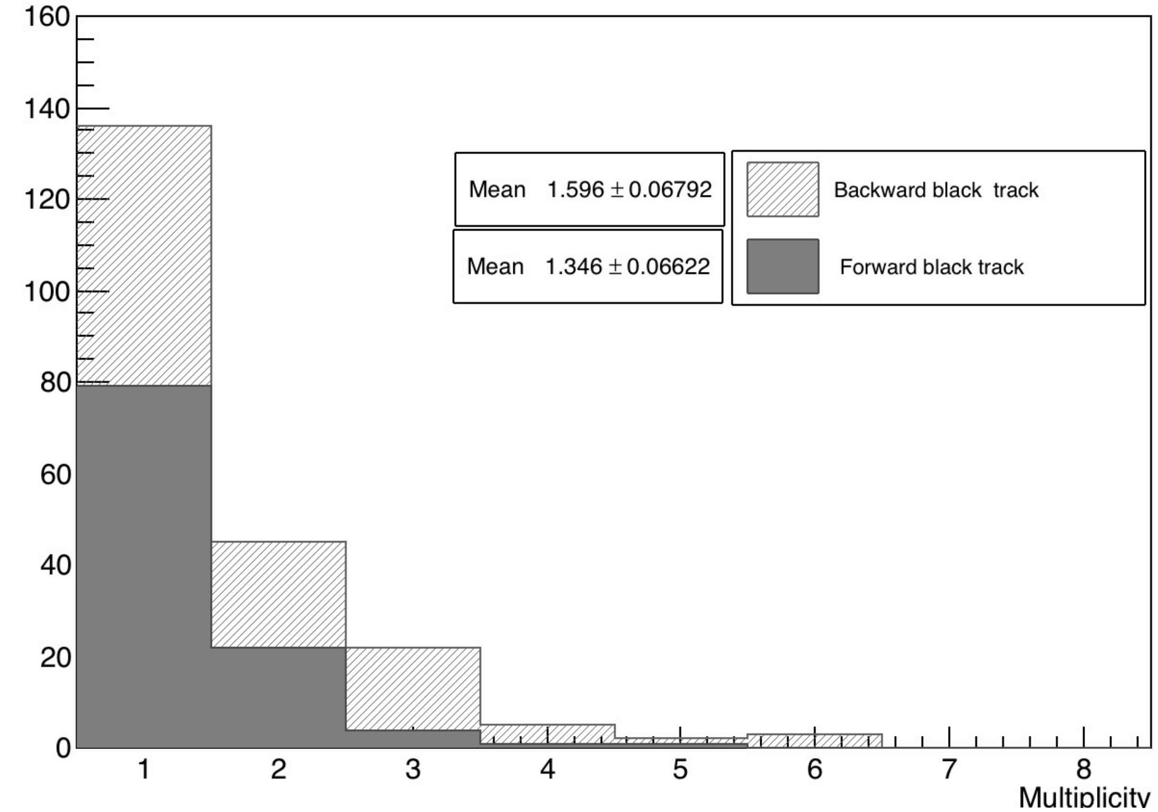
Number of Hadron Tracks Specific Energy Ranges

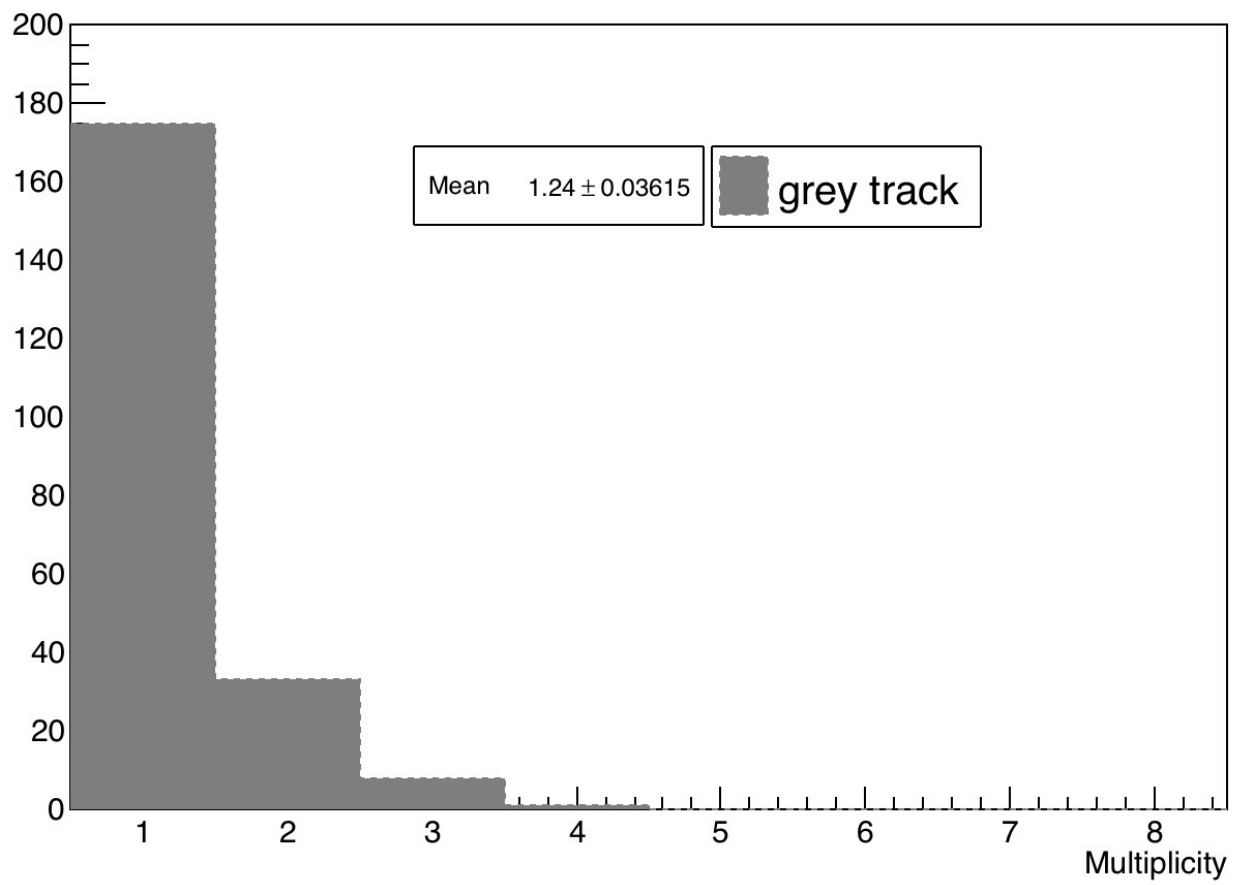
Variables			Number of hadron tracks											
$W^2(GeV)^2/c^4$	$\langle W^2(GeV)^2/c^4 \rangle$	$\langle n_{ch} \rangle$	0	1	2	3	4	5	6	7	8	9	10	>11
1-3	1.98 ± 0.07	0.82 ± 0.08	44	37	20	2	0	1	0	0	0	0	0	0
3-6	4.54 ± 0.10	1.50 ± 0.11	19	53	32	8	3	2	3	0	0	0	0	0
6-10	1.78 ± 0.11	7.92 ± 0.11	18	62	28	19	14	5	1	0	0	0	0	0
10-14	12.31 ± 0.11	2.18 ± 0.11	8	43	47	36	12	5	2	1	0	0	0	0
14-18	15.71 ± 0.12	2.26 ± 0.11	8	34	52	28	10	7	2	1	1	0	0	0
18-24	20.55 ± 0.19	2.57 ± 0.13	5	27	36	30	15	6	4	3	0	0	0	0
24-32	27.10 ± 0.24	2.70 ± 0.14	1	23	22	28	13	8	3	1	0	0	0	0
32-45	37.10 ± 0.49	3.32 ± 0.23	1	7	17	11	10	6	5	3	1	0	0	0
45-63	52.35 ± 1.16	3.96 ± 0.34	1	3	2	5	11	3	2	2	2	0	0	0
>63	89.80 ± 5.1	4.46 ± 0.33	0	1	3	6	10	2	6	2	1	0	1	1

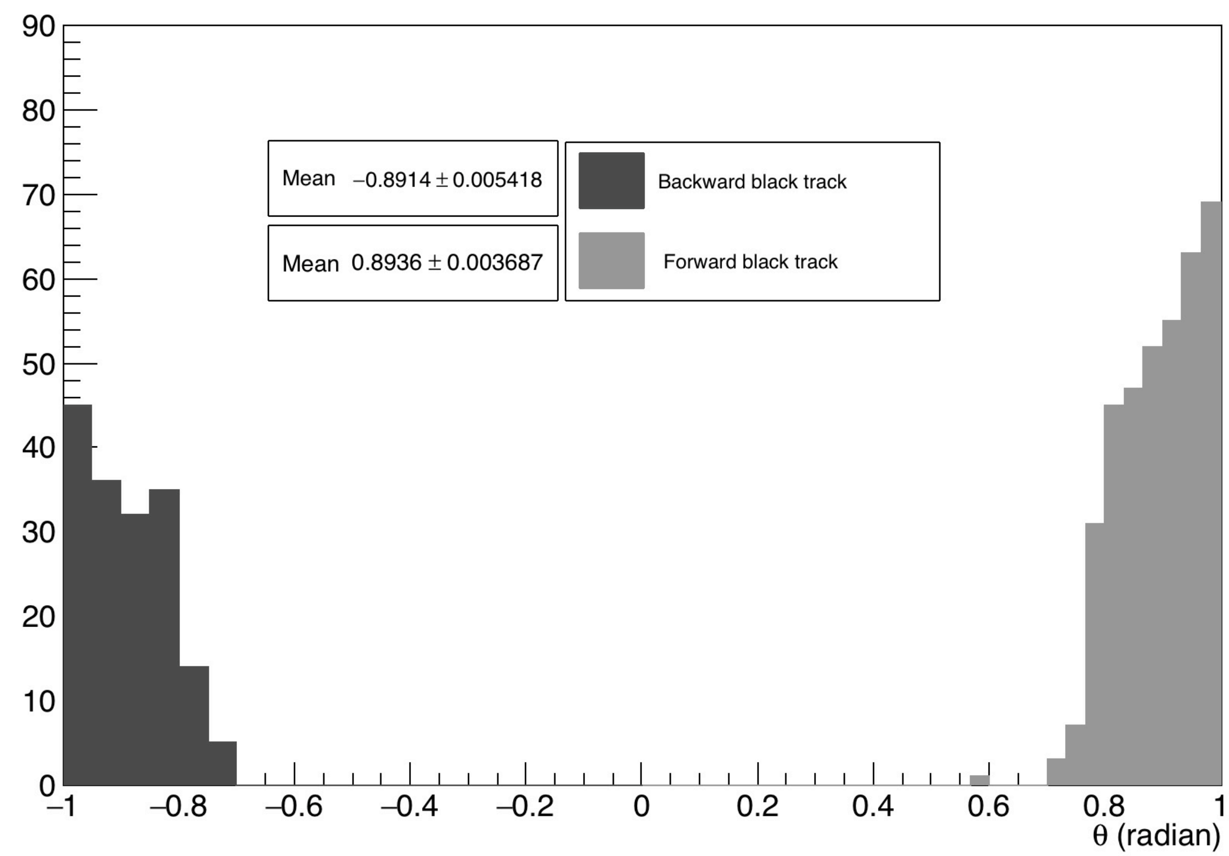
DataSample(2010 – 2012)			
θ(Radian)	$\langle \theta \rangle$	Number of tracks(Ntr)	Ntr/Nevents
0.00 ÷ 0.050	0.033 ± 0.001	49	0.14
0.050 ÷ 0.100	0.077 ± 0.001	90	0.25
0.100 ÷ 0.150	0.127 ± 0.001	132	0.37
0.150 ÷ 0.200	0.172 ± 0.001	127	0.36
0.200 ÷ 0.300	0.241 ± 0.002	154	0.44
0.300 ÷ 0.400	0.345 ± 0.003	81	0.23
0.400 ÷ 0.500	0.446 ± 0.004	45	0.12
0.500 ÷ 0.600	0.540 ± 0.006	24	0.06
> 0.600	0.760 ± 0.03	22	0.04

Heavy Track Multiplicity Distributions

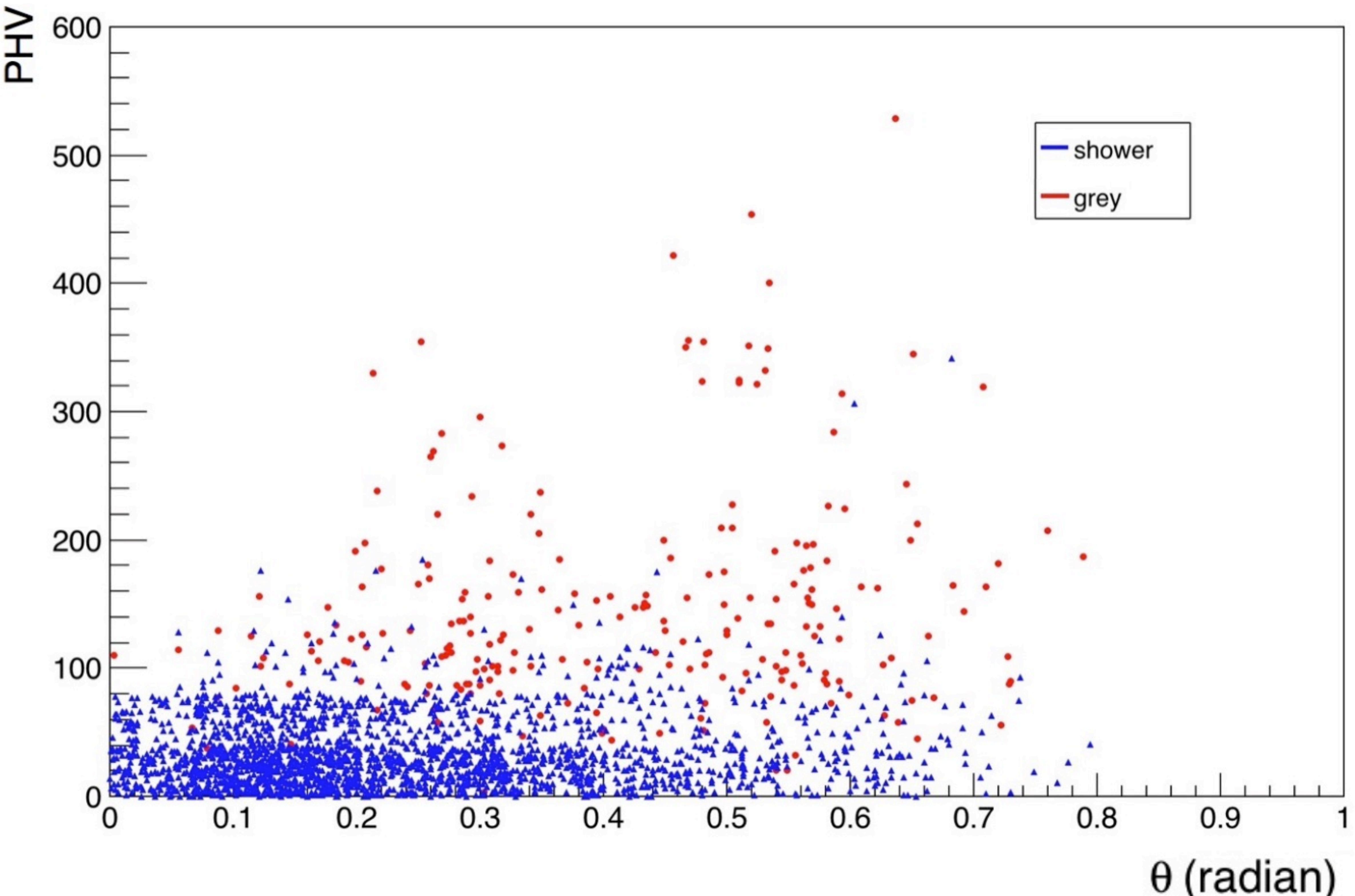
Track	**MeanMultiplicity** $\langle \mathbf{n} \rangle$
Hadron	2.47 ± 0.10
Grey	1.24 ± 0.03
Forward Black	1.59 ± 0.06
Backward Black	1.34 ± 0.06







PHV


PHV
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
θ (radian)
shower
grey

Location efficiency cross check (Giuliana/Svetlana)

OPERA PC, 25/02/2016

- total: check the trees and variables in the file
- ED trigger
- classification: 0μ - μid !=1 && track_length $<$ 20
- OpCarac: CONTAINED or BORDERSOFTNC
- BF: 1st-4th bricks (1st-2nd bricks and $P_\mu < 15$ GeV or 3rd-4th bricks and $P_\mu < 5$ GeV)
- CS: muon, vertex or CS-TT connection
- SB: reach a primary vertex within 5 plates
- Loc: 1<=vtxplate<=54

ν_μ CC 1μ	Giuliana:	eff(%)	Svetlana:	eff(%)	Çağın	eff(%)
total	21309	100 ± 0	21801	100 ± 0	11000	100±0
ED Trigger	21309	100 ± 0	21801	100 ± 0	11000	100±0
Classification	20308	95.30 ± 0.14	20736	95.11 ± 0.15	10248	93.16±0.11
OpCarac	19798	92.91 ± 0.18	20209	92.70 ± 0.18	10000	90.90±0.13
BF	12628	59.26 ± 0.34	13461	61.74 ± 0.33	6333	57.57±0.36
CS	10756	50.48 ± 0.34	10850	49.77 ± 0.34	5516	50.14±0.35
SB	10543	49.48 ± 0.34	10658	48.89 ± 0.34	5500	50.00±0.37
LOC	9915	46.53 ± 0.34	10017	45.95 ± 0.33	5276	47.96±0.36

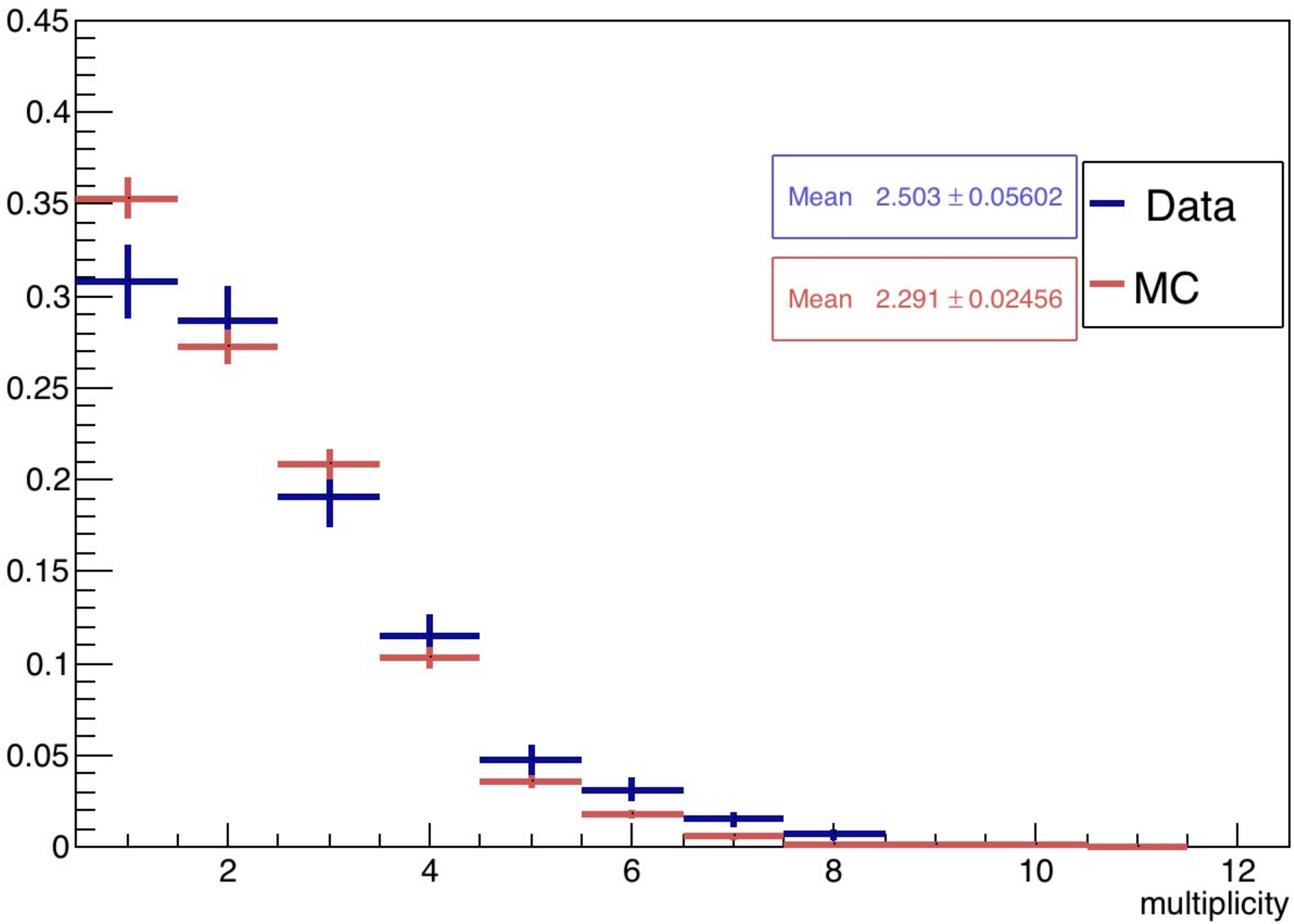
Location Efficiency

ν_μ CC-DIS + ν_μ CC-QE + ν_μ NC

10 ▲ *0.82* ▲ *0.74*

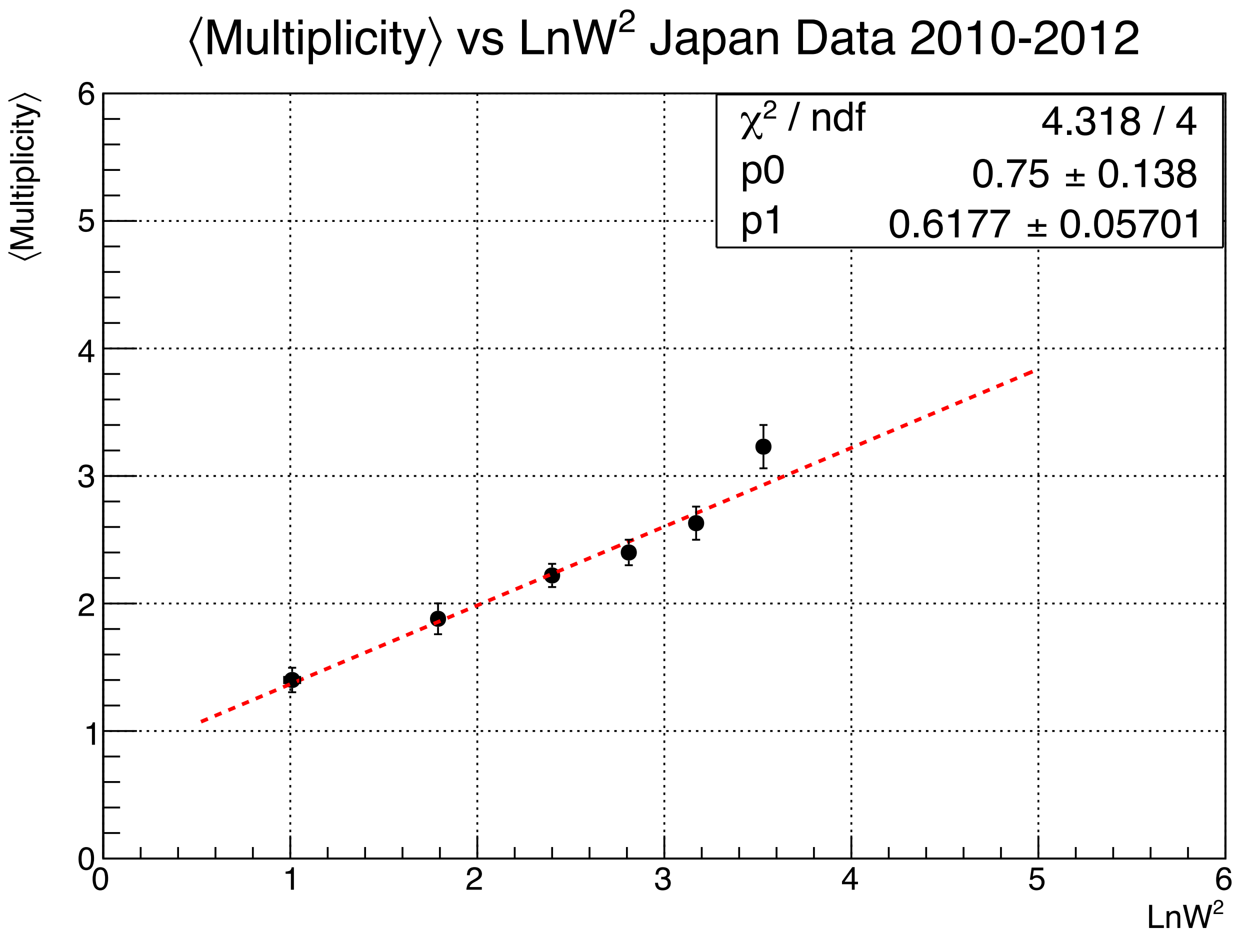
$W^2 (GeV)^2/c^4$	$n_{ch} = n_s - 1$						
	0	1	2	3	4	5	*All*
1-3	0.47 ± 0.02	0.53 ± 0.02	0.60 ± 0.02	0.60 ± 0.02	0.50 ± 0.05	0.52 ± 0.02	0.52 ± 0.01
3-6	0.42 ± 0.02	0.47 ± 0.02	0.58 ± 0.03	0.64 ± 0.02	0.55 ± 0.01	0.58 ± 0.08	0.49 ± 0.01
6-10	0.43 ± 0.03	0.50 ± 0.02	0.59 ± 0.01	0.60 ± 0.02	0.60 ± 0.03	0.59 ± 0.05	0.52 ± 0.01
10-14	0.36 ± 0.03	0.49 ± 0.02	0.57 ± 0.01	0.58 ± 0.01	0.58 ± 0.04	0.50 ± 0.07	0.51 ± 0.01
14-18	0.41 ± 0.03	0.49 ± 0.02	0.59 ± 0.01	0.61 ± 0.02	0.53 ± 0.03	0.59 ± 0.03	0.53 ± 0.01
18-24	0.37 ± 0.04	0.55 ± 0.02	0.58 ± 0.01	0.65 ± 0.02	0.58 ± 0.02	0.59 ± 0.03	0.57 ± 0.01
24-32	0.45 ± 0.05	0.50 ± 0.02	0.55 ± 0.02	0.61 ± 0.02	0.55 ± 0.02	0.62 ± 0.02	0.55 ± 0.01
32-45	0.43 ± 0.05	0.42 ± 0.02	0.50 ± 0.03	0.55 ± 0.02	0.60 ± 0.02	0.57 ± 0.03	0.51 ± 0.01
45-63	0.48 ± 0.05	0.43 ± 0.02	0.43 ± 0.04	0.48 ± 0.05	0.63 ± 0.01	0.52 ± 0.05	0.49 ± 0.01
>63	0.42 ± 0.02	0.33 ± 0.02	0.33 ± 0.05	0.39 ± 0.04	0.46 ± 0.05	0.49 ± 0.04	0.40 ± 0.01
All	0.42 ± 0.01	0.56 ± 0.01	0.56 ± 0.01	0.59 ± 0.01	0.58 ± 0.01	0.56 ± 0.01	0.52 ± 0.01

Data-MC

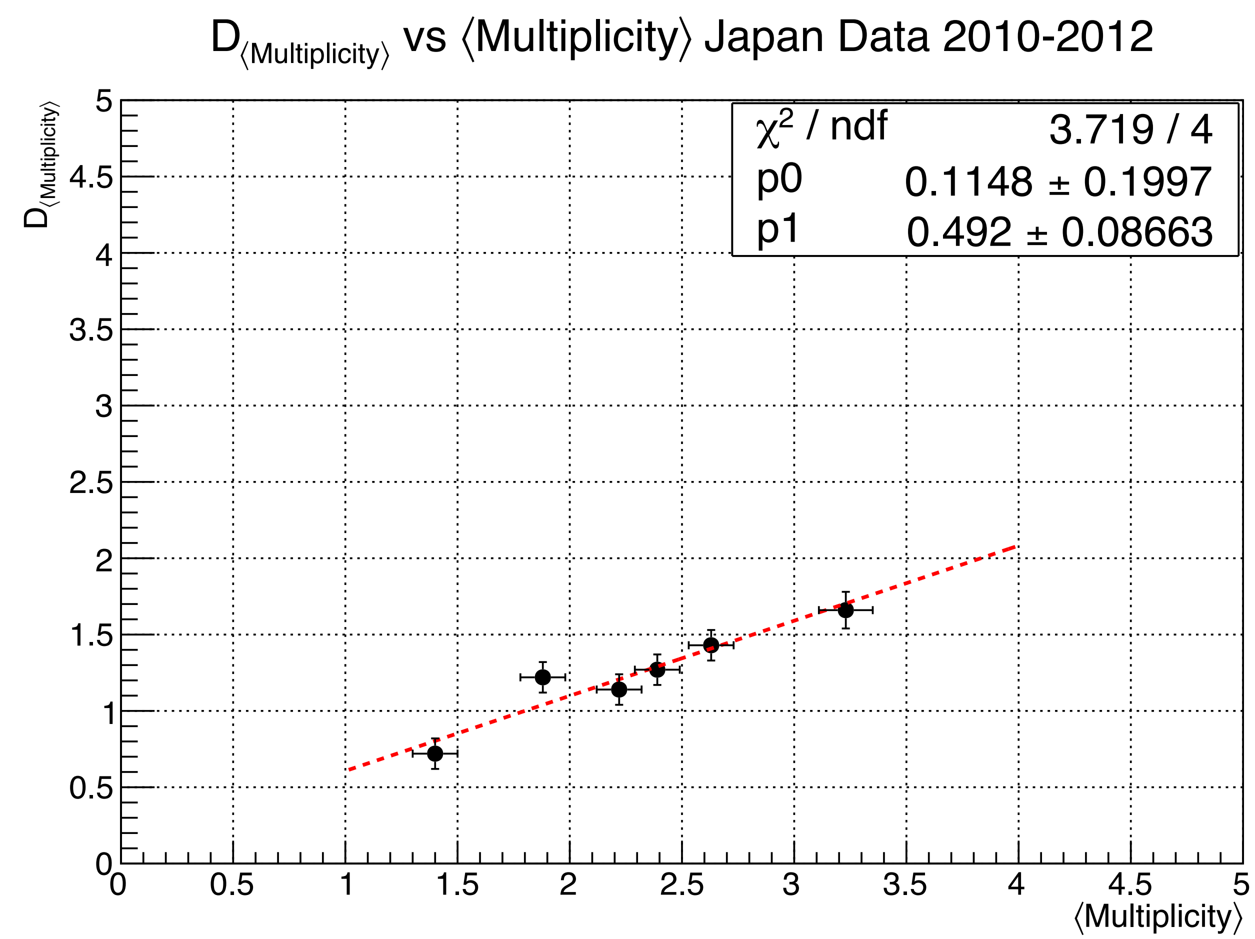


0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2
4
6
8
10
12
multiplicity
Mean 2.503 ± 0.05602
Mean 2.291 ± 0.02456
Data
MC

⟨Multiplicity⟩ vs LnW^2 and Dispersion

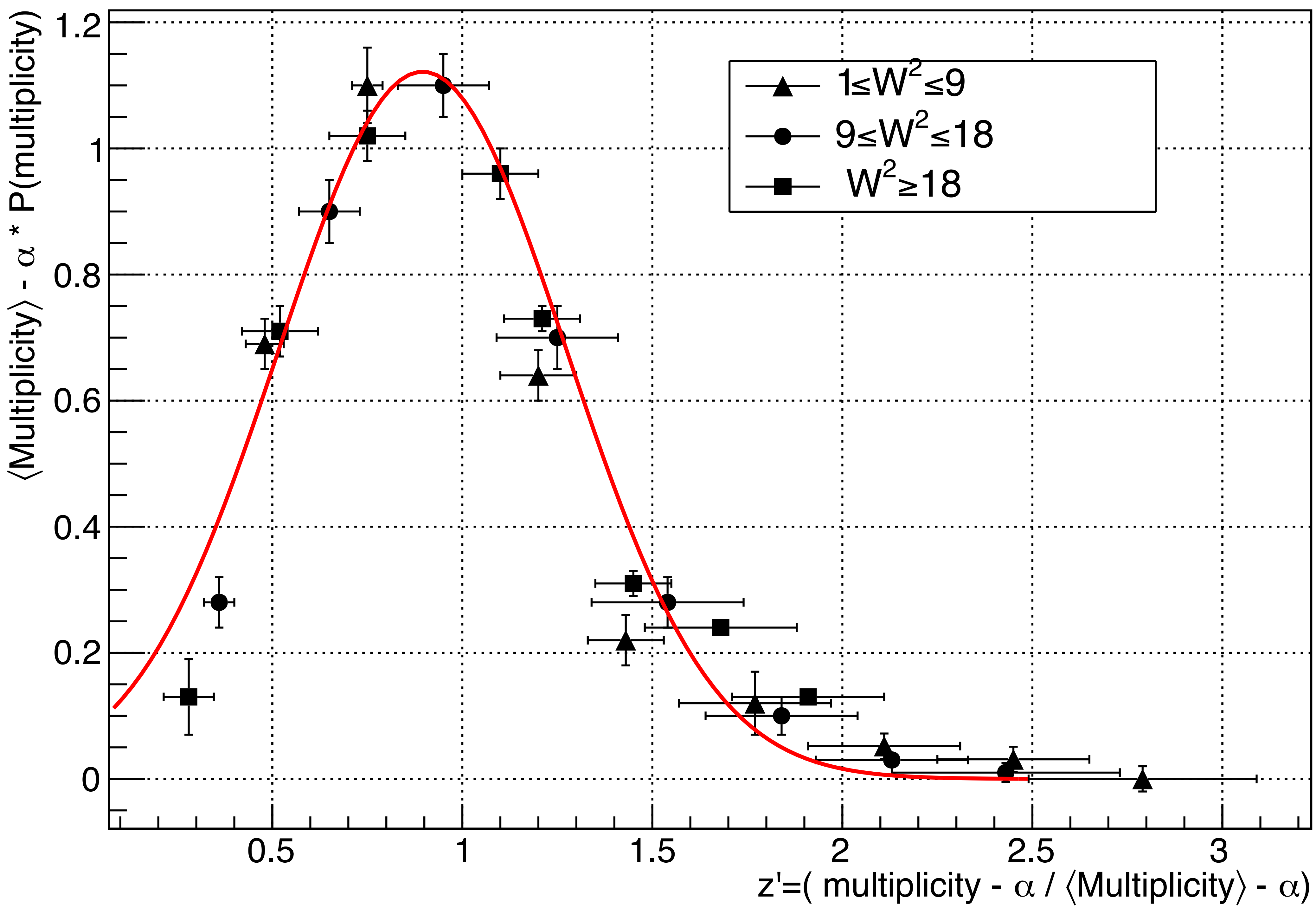


$$\langle Multiplicity \rangle = (0.75 \pm 0.13) + (0.61 \pm 0.05)\, Ln(W^2)$$



$$D_{\langle Multiplicity \rangle} = (0.11 \pm 0.19) + (0.49 \pm 0.08) \langle Multiplicity \rangle$$

KNO Scaling



⟨Multiplicity⟩ - α * P(multiplicity)
1.2
1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
2.5
3
z'=(multiplicity - α / ⟨Multiplicity⟩ - α)
1≤W2≤9
9≤W2≤18
W2≥18

Internal Note

Study of Charged Particle Multiplicity Distributions in High Energy Neutrino-Lead Interactions in the OPERA Detector

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Abstract

In this note, we report a study of charged particle multiplicities initiated in high energy charged current neutrino interactions in the OPERA detector. We present charged particle average multiplicities, the dispersion and investigate the KNO scaling in different kinematical regions based on event-by-event analysis. The results are presented in a form suitable for use in the validation of Monte Carlo generators of neutrino-lead interactions.

1 Introduction

The mean multiplicity of charged hadrons is an important characteristics of the final hadron states in hard scattering processes. It reflects the dynamics of the interaction process. Therefore, mean multiplicity of charged hadrons has been studied extensively in cosmic rays, fixed target and collider experiments (give ref). These data are useful to improve models of particle productions which are available as Monte Carlo event generators.

In this paper, we report the results on charged-hadron production initiated in high energy charged-current neutrino interactions:

$$\nu_\mu + n \to \mu^- + X^+, X^+ \to hadrons$$

$$\nu_\mu + p \to \mu^- + X^{++}, X^{++} \to hadrons$$

The basic unit of the OPERA target is ECC bricks, which are stacks of interleaved emulsion films and lead plates. Emulsion films act as high precision trackers while lead plates provide a massive target for neutrino interactions. The excellent spatial resolution of nuclear emulsion allows the identification of event topology and measurement of trajectory of charged particles. Therefore, it is well suited for the investigation of the multiplicity moments of charged particles. However, only few studies of charged-particle multiplicity in neutrino-nucleon interactions were made with nuclear emulsion technology.

In the following, a short description of the OPERA experimental setup and of the procedure used to locate neutrino interactions in the OPERA target is given, the data sample and analysis are described. Then, multiplicity moments and investigation of KNO scaling in different kinematical regions based on event-by-event measurement will be presented in a form suitable for use in the validation of Monte Carlo generators of neutrino−lead interactions.

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Internal Note

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Files	Doc	Ver	Date	Authors	Title	Class
*****	184	1	26-Oct-2016	C. Kamiscioglu, M. Guler	Study of Charged Particle Multiplicity Distributions in High Energy Neutrino-Lead Interactions in th	draft
*****	183	1	21-Mar-2016	Bologna Padova Group	A neutrino interaction with two secondary decay vertices at short distance	innote
*****	182	1	18-Jan-2016	A. Longhin, A. Paoloni, F. Pupilli	Limits on Neutral Current Non-Standard neutrino Interaction (NSI) parameters from OPERA results	innote
*****	181	1	27-Oct-2015	S. Dusini, G. Sirri, M. Tenti	Search for sterile neutrino mixing in the nu_mu -> nu_tau appearance channel. Update: October 2015	innote
*****	180	2	30-Sep-2015	A. Longhin, A. Paoloni, F. Pupilli	Limits on the existence of a fourth sterile neutrino from OPERA results on tau appearance	innote
*****	180	1	29-Sep-2015	A. Longhin, A. Paoloni, F. Pupilli	Limits on the existence of a fourth sterile neutrino from OPERA results on tau appearance	innote
*****	179	4	13-Jul-2015	T. Fukuda	Measurements of charged particles ionization loss with grain counting in the OPERA emulsion film	innote
*****	179	3	11-Jul-2015	T. Fukuda	Measurements of charged particles ionization loss with grain counting in the OPERA emulsion film	innote
*****	179	2	09-Jul-2015	T. Fukuda	Measurements of charged particles ionization loss with grain counting in the OPERA emulsion film	innote
*****	179	1	30-Jun-2015	T. Fukuda	Measurements of charged particles ionization loss with grain counting in the OPERA emulsion film	innote
*****	178	1	22-Jun-2015	A. Chukanov, S. Zemskova	OPERA neutrino beam spectrum correction with the usage of the modern cross-section data	innote
*****	177	1	11-May-2015	A.Longhin, A.Paoloni, F.Pupilli	Large-angle scattering of multi-GeV muons on thin Lead targets	innote

Conclusion

-Multiplicity of charged particles, dispersion in multiplicity and KNO scaling have been studied

-Dependance of average multiplicity on LnW^2 shows linear dependence,

-The dispersion of the multiplicty also shows a linear depedence on mean multiplicity,

-Results are summarised in an OPERA internal note


Thank You!

5.5.3. Kamıscıoglu,Ç.(2016). " Multiplicity Distributions of OPERA Experiment", International Symposium on EcoTopia Science 2015, November 27-29, 2015, Nagoya University, Nagoya, Japan

5.3.14. Kamıscıoglu,Ç.(2016)."MULTIPLICITY DISTRIBUTIONS IN CHARGE -CURRENT NEUTRINO INTERACTIONS" **OPERA Collaboration Meeting - Nagoya -March 30-April 1, 2016**

5.3.15. Kamıscıoglu,Ç.(2016)."Multiplicity Distributions in Charge Current Neutrino Interactions" **OPERA PC Meeting - Nagoya -May 12-2016**