

# **Evaluation of Charged Particle Multiplicity in Fragmentation Reactions Induced by Therapeutic $^{12}\text{C}$ Beams**

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**6) CREST, JST**

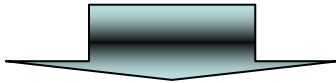
# Introduction

## ◆ Carbon Beam Therapy

Cancer therapy using high-energy carbon beams has been successfully under way at HIMAC since 1994.

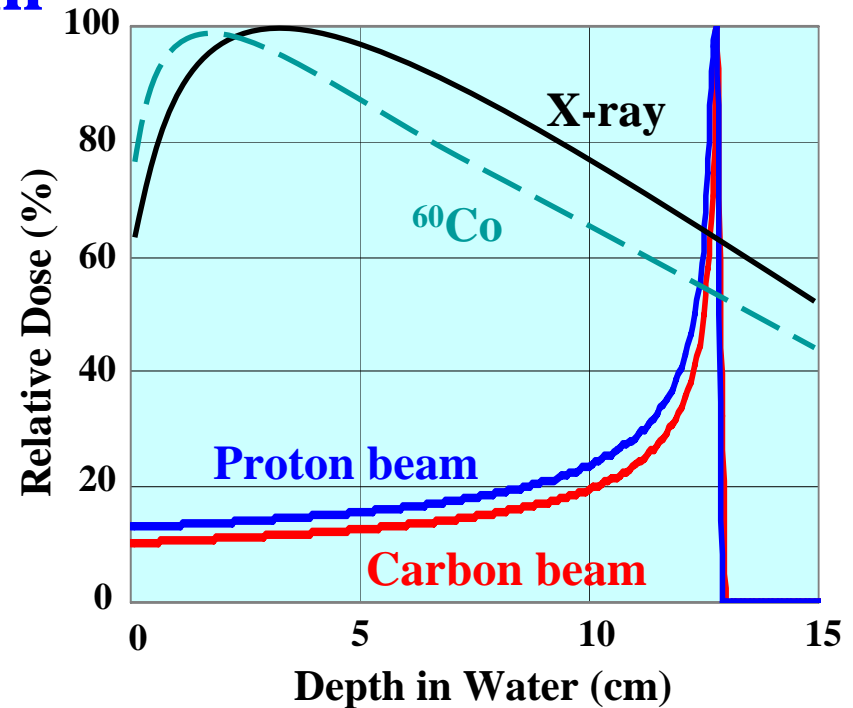
## ◆ Advantages of Carbon Beam

### Bragg Peak & High LET



➤ Excellent dose concentration

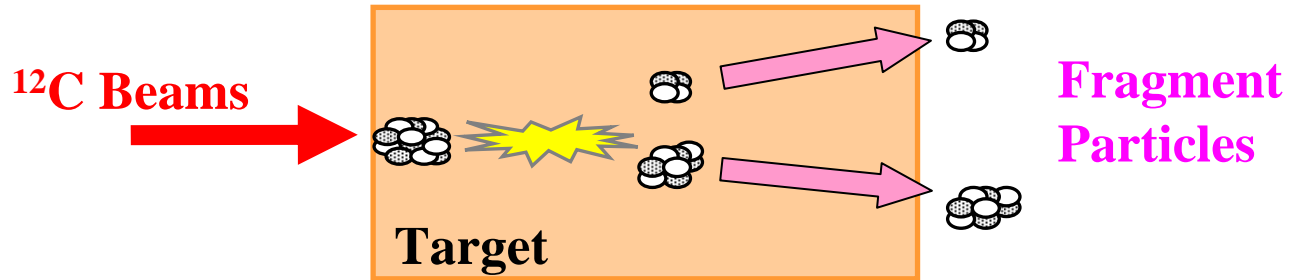
➤ High RBE, Low OER



Depth dose distribution of various radiations

# Introduction

## ◆ Fragmentation Reaction



Fragmentation reaction in the target

A part of incident  $^{12}\text{C}$  nuclei and target nuclei are broken into lighter ions such as proton, lithium or boron.

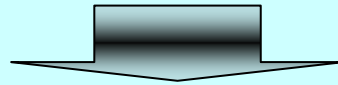
## ◆ Charged Particle Multiplicity

The number of charged particles generated by fragmentation reactions.

# *Introduction*

## ◆ Theoretical Model of Fragmentation Reaction : JQMD

JQMD ( Jaeri QMD) is a QMD code developed by JAERI ( Japan Atomic Energy Research Institute).



**QMD (Quantum Molecular Dynamics) model is widely used to analyze various aspects of heavy ion reactions.**

**JQMD includes SDM (Statistical Decay Model), SDM is used for evaporation and fission decays of excited nuclei.**

**In order to apply JQMD to treatment planning for  $^{12}\text{C}$  cancer therapy, its verification is in progress.**

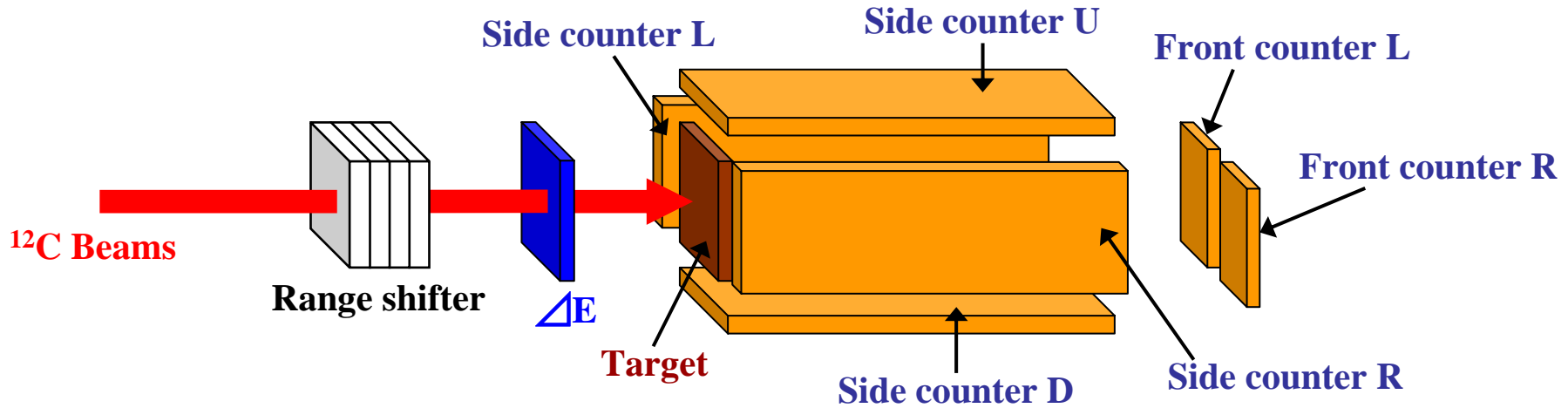
# *Purpose*

**We estimate the charged particle multiplicity in fragmentation reactions.**

➤ **The results are compared with the theoretical calculation using Geant4 which installed JQMD.**

# Methods

## ◆ Measuring Devices



$\Delta E$ : Identification of incident particles

Side counter (4)

Front counter (2)

Fragment particle  
detectors

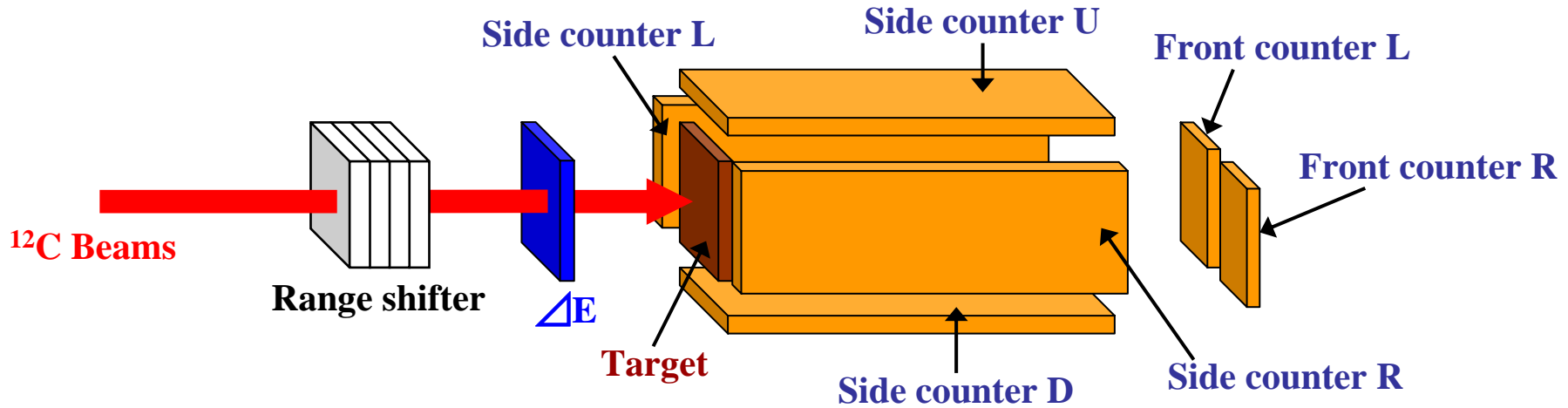
Made of plastic  
scintillator

Materials used for the target : Graphite, Plastic Scintillator ( $\text{C}_9\text{H}_{10}$ )

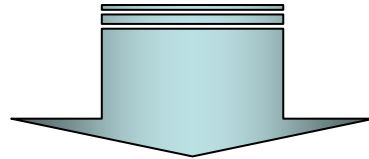
Beam energy : 300 [MeV/u] (Range shifter : 50.16 [mm] (PMMA))

# Methods

## ◆ Definition of Multiplicity in This Measurement



The charged particle multiplicity defined in this measurement is the number of signals obtained from the **fragment particle detectors**.



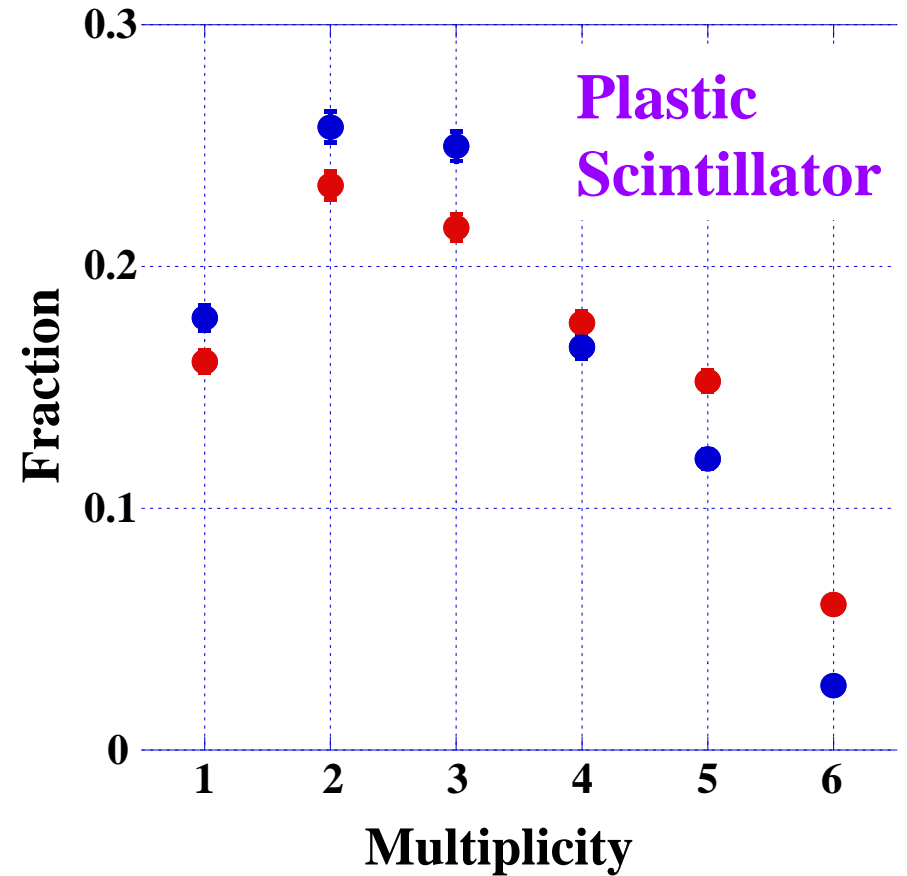
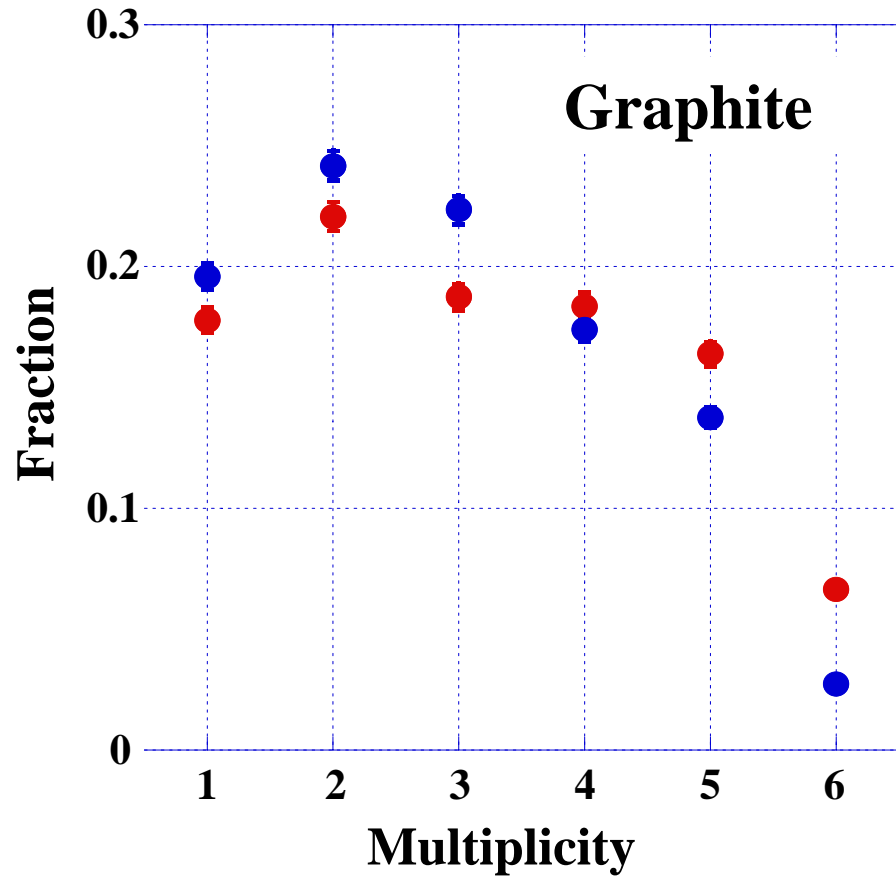
when signals come from any three of the fragment particle detectors,



**The multiplicity is defined as three.**

# Results

## ◆ Fractions of Charged Particle Multiplicities

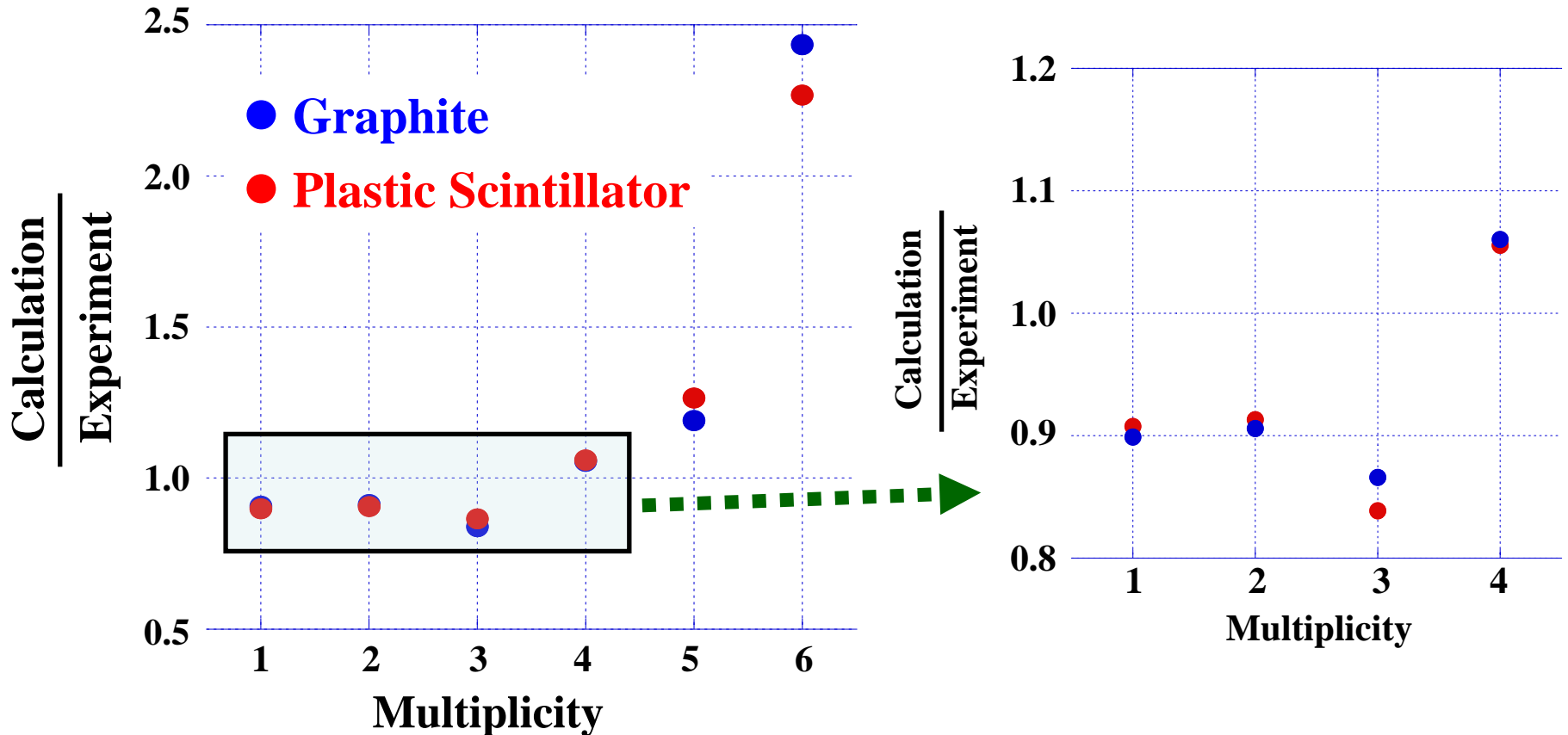


● Experiment

● Calculation

# Results

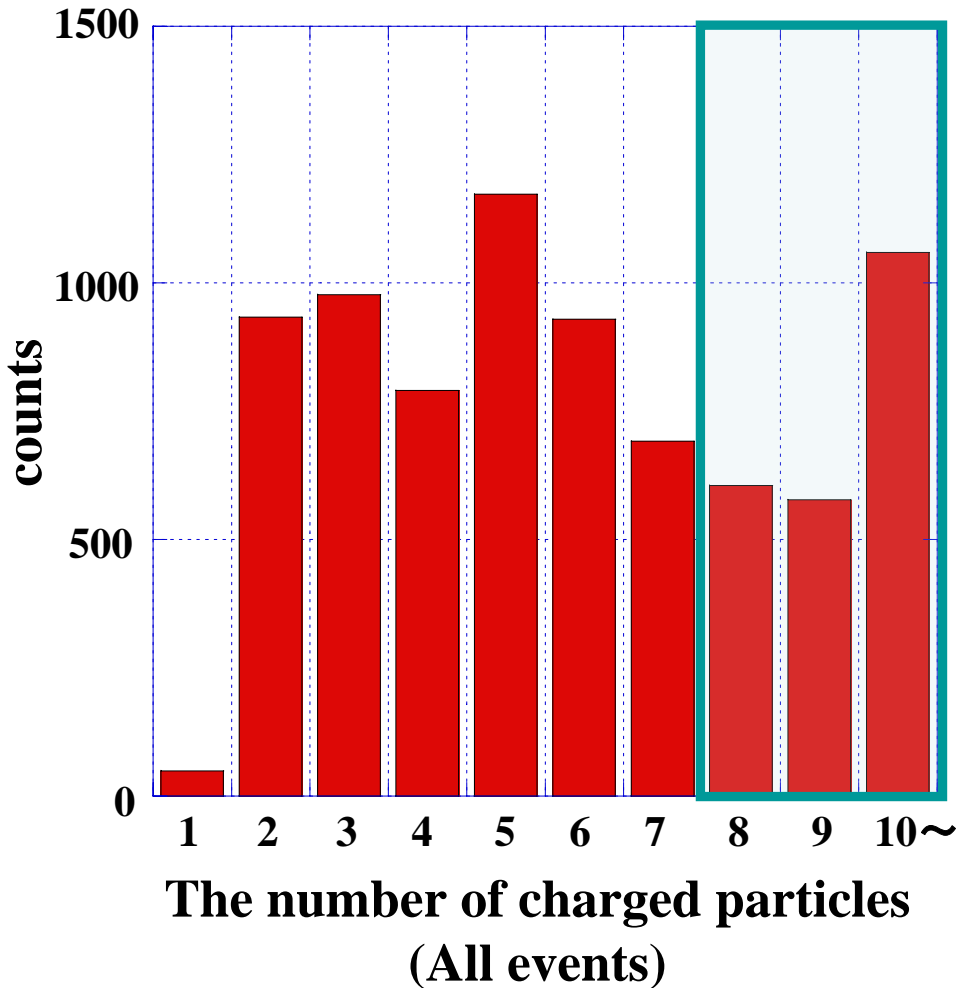
## ◆ Comparison of Experiment and Calculation



**The experimental distribution of charged particle multiplicity is not reproduced by the calculations.**

# Discussion

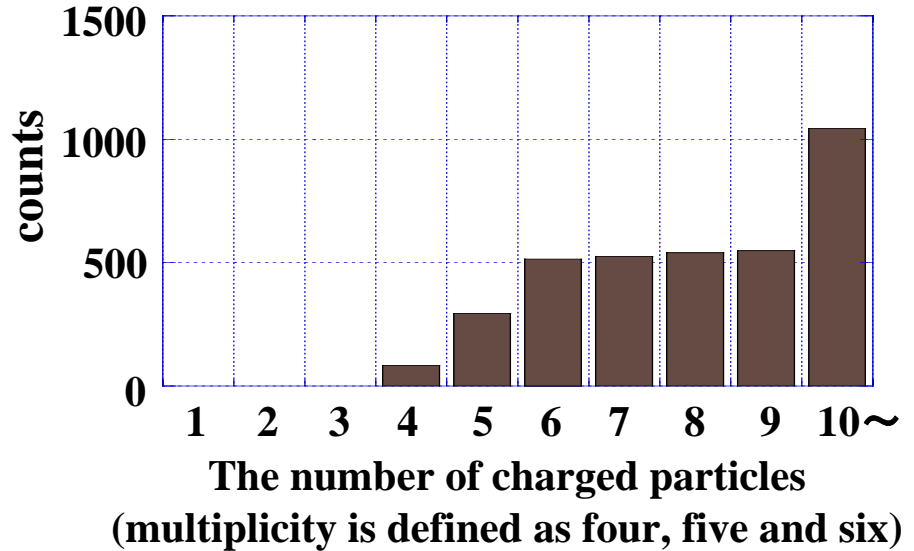
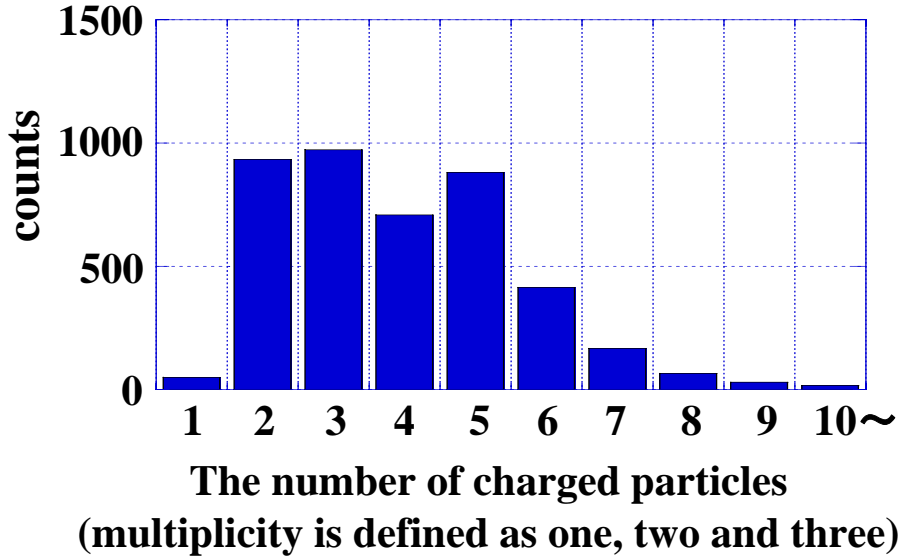
## ◆ The Number of Generated Charged Particles : Calculation



**A lot of charged particles are generated.**

# Discussion

## ◆ The Number of Generated Charged Particles : Calculation



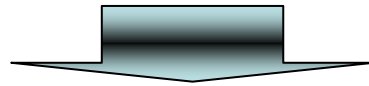
**The number of generated charged particles is overestimated.**

➤ **The events whose number of generated charged particles is two, three and four are underestimated.**

# *Conclusion*

**We estimate the charged particle multiplicity in fragmentation reactions.**

➤ **The results are compared with the theoretical calculation using Geant4 which installed JQMD.**



**The experimental distribution of charged particle multiplicity is not reproduced by the calculations.**



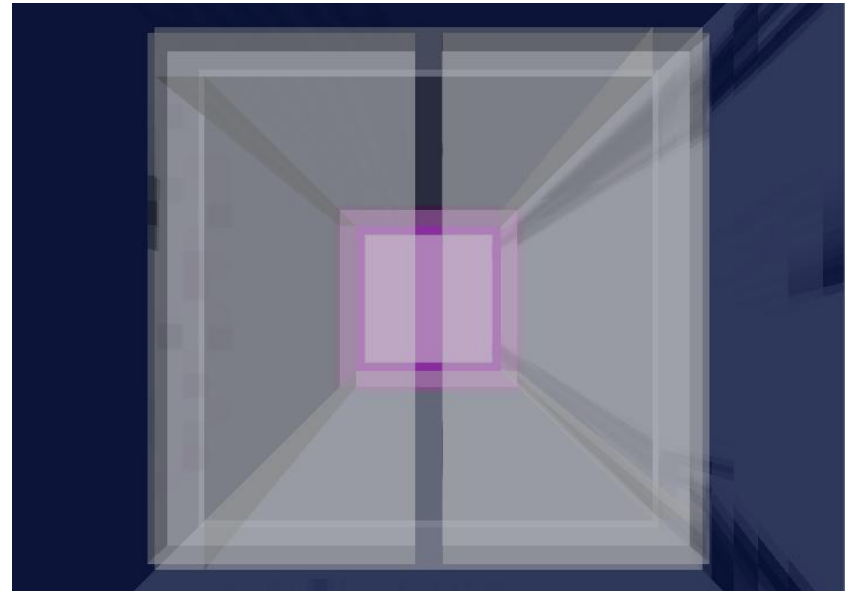
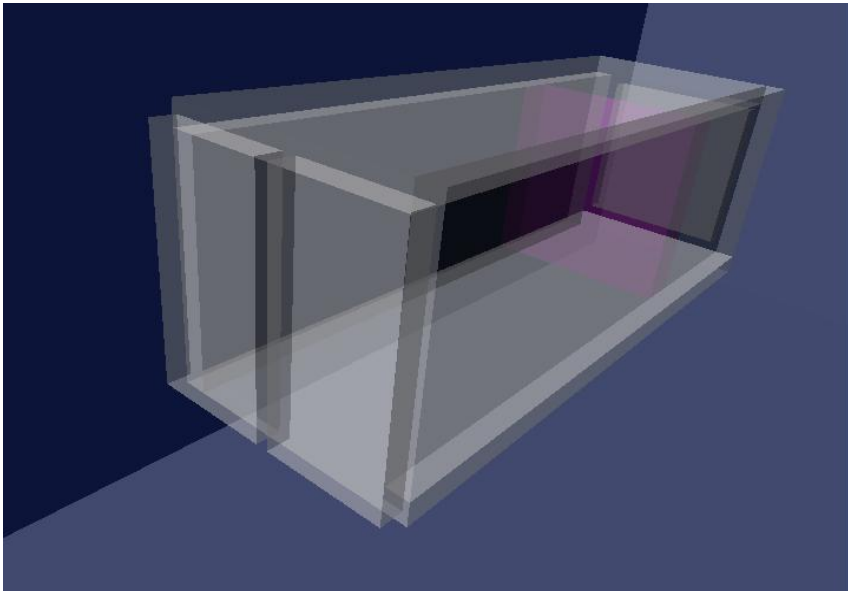
# *Methods*

## ◆ Condition of Simulation

➤ **SUSE LINUX 9.3**

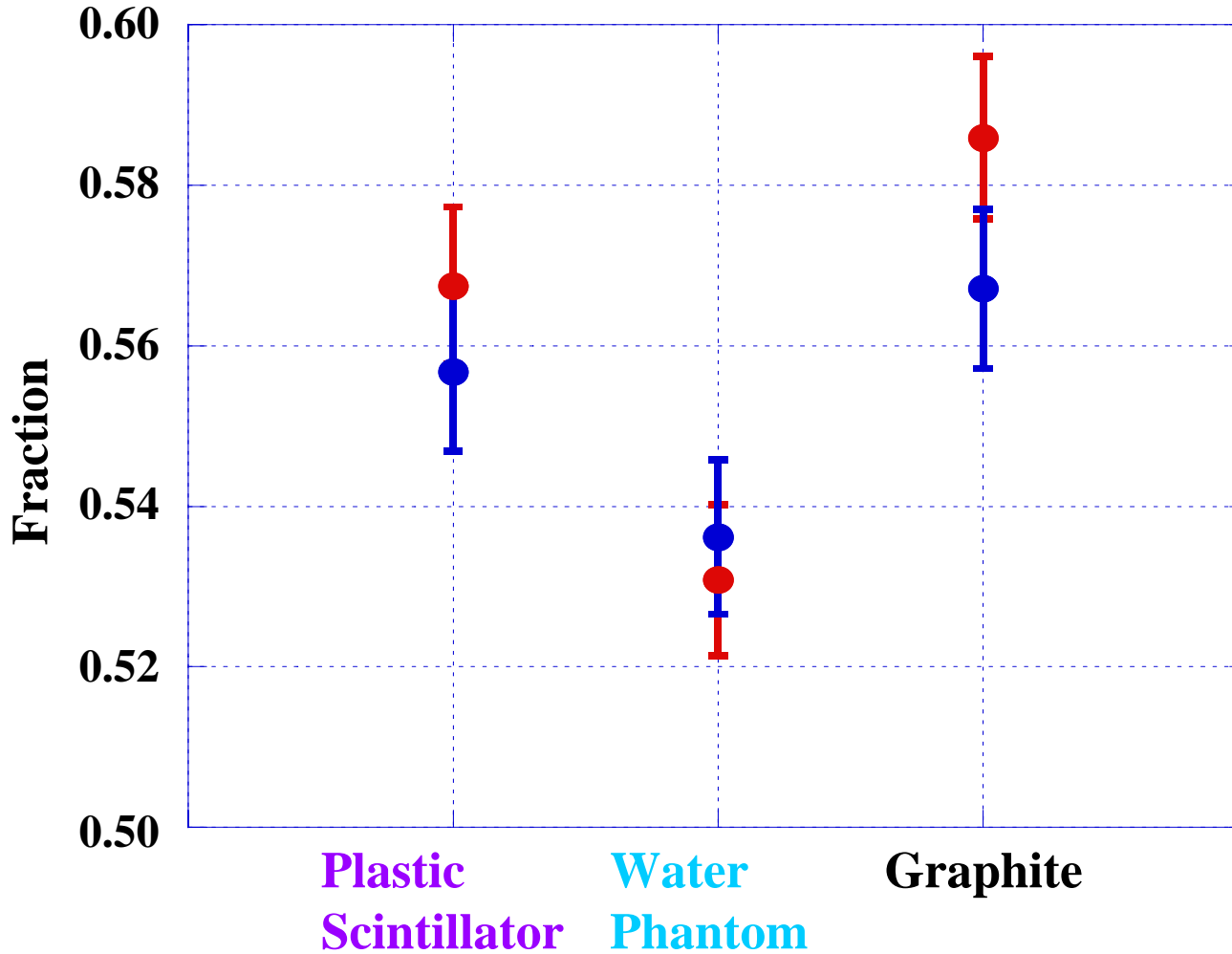
➤ **Geant4.7.1.p01**

➤ **CLHEP 1.9.2.1**



# Results

## ◆ Fraction of Fragmentation Reaction



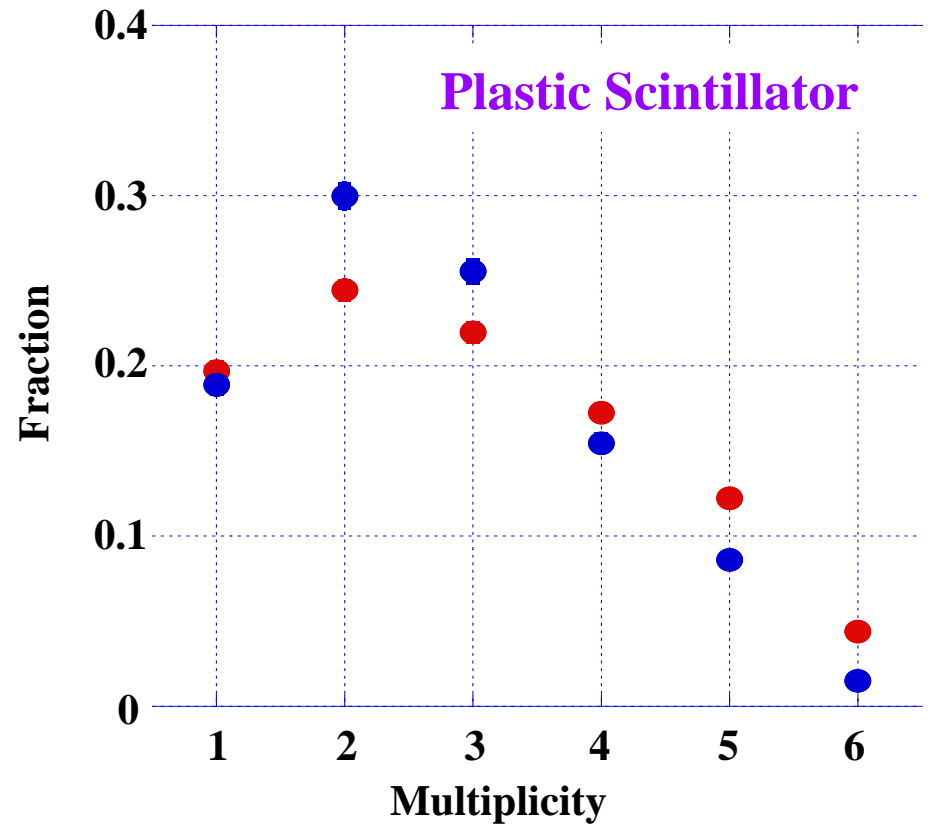
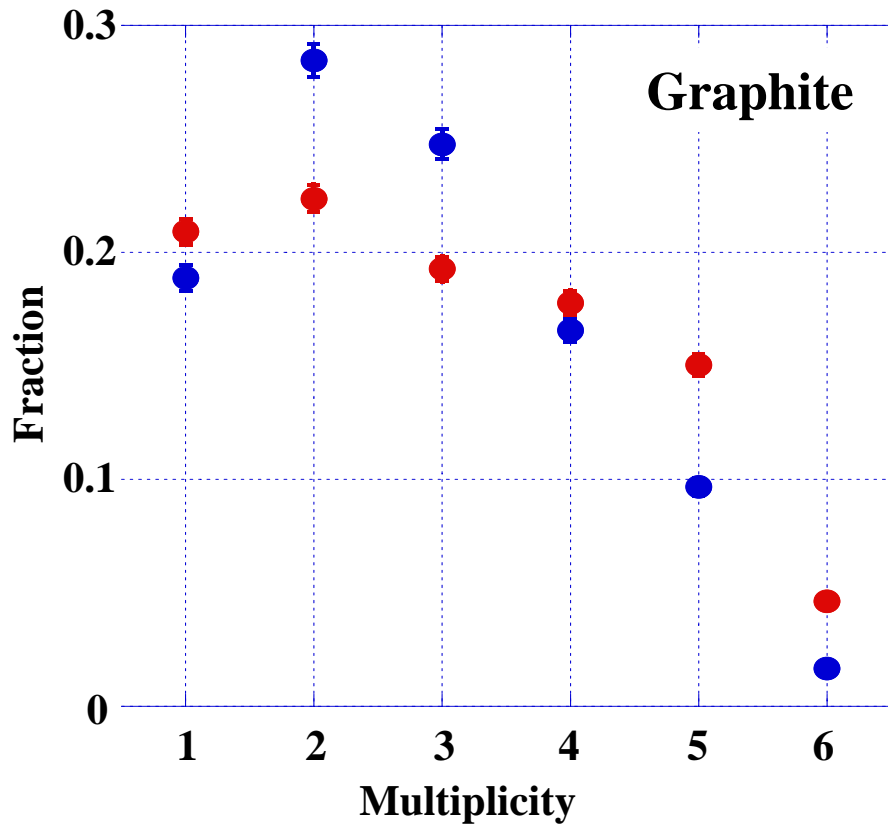
● Experiment  
● Calculation

Energy of  $^{12}\text{C}$  beam  
is 345[MeV/u]

# Results

## ◆ Fractions of Charged Particle Multiplicities

: 200 [MeV/u]



● Experiment ● Calculation