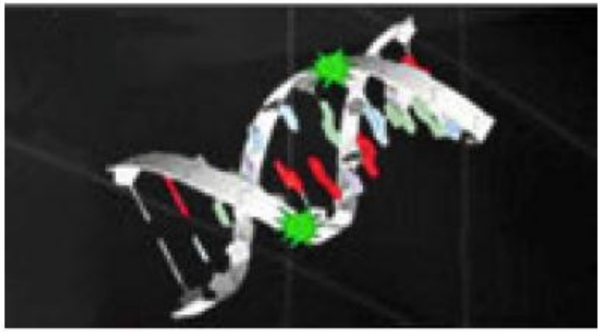

COST Action MP1002 Nanoscale Insights into Ion Beam Cancer Therapy (NanoIBCT)

European Radiation Dosimetry Group e. V. WG 6 Computational Dosimetry

EMRP Project Biologically Weighted Quantities in Radiotherapy

MiND – IBCT Workshop Wiener Neustadt (Austria), 07-09 May 2014

EXPERIMENTAL NANODOSIMETRY OF CARBON IONS

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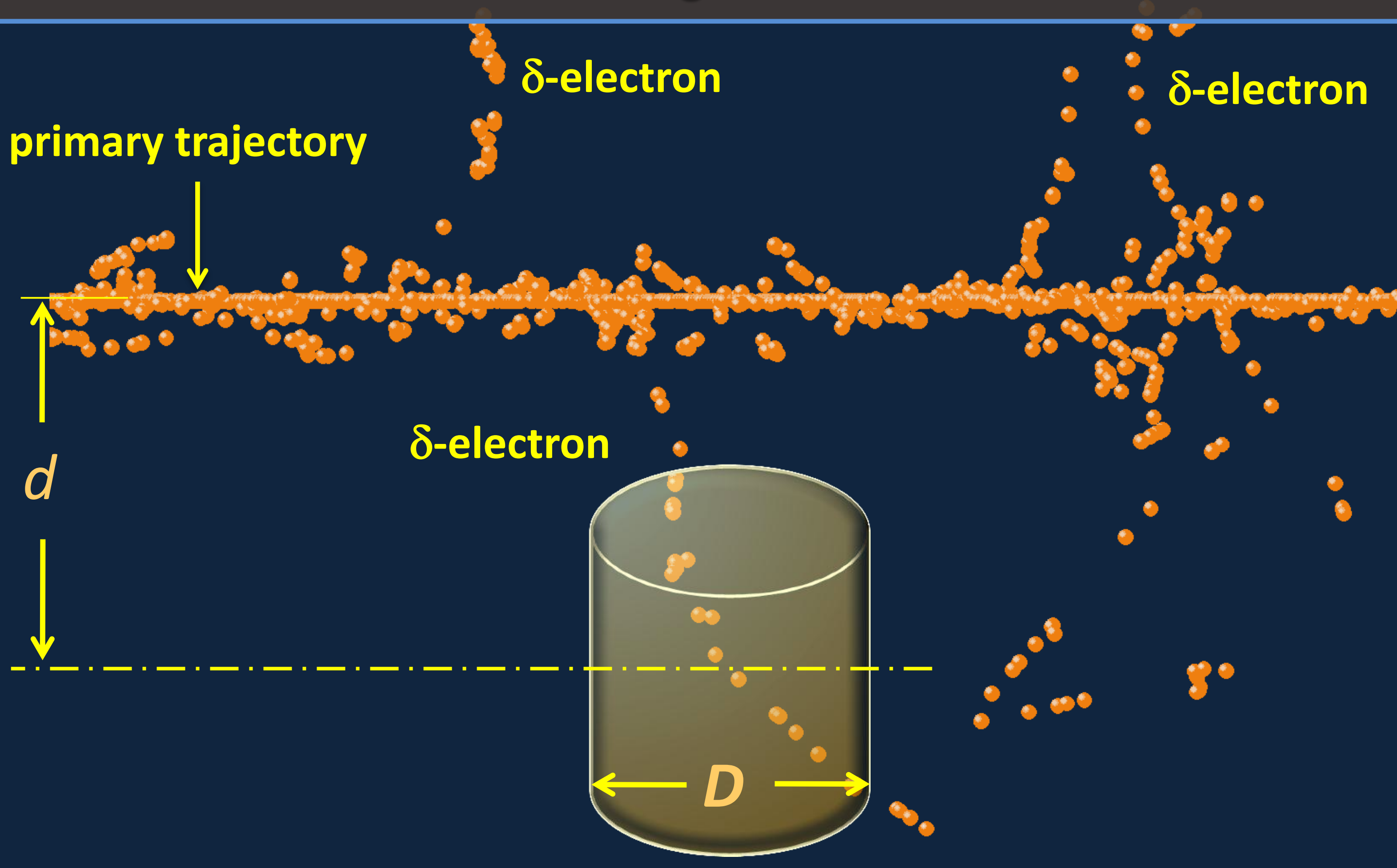
Outline:

- The track-nanodosimeter of the Legnaro National Laboratories
  Description of the measuring device

- Properties of the track structure of 96 MeV, 150 MeV and 240 MeV carbon-ions (results of several measurement campaigns at LNL)

RATIONAL OF THE EXPERIMENT

A narrow parallel particle beam is passing a cylindrical target volume of diameter D, at impact parameter d. And the number ν of ionizations inside the target volume is counted



RATIONAL OF THE EXPERIMENT

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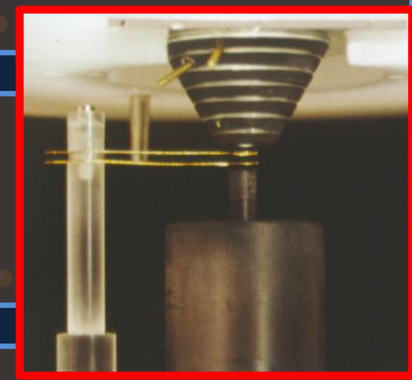
Pencil beam: the impact parameter *d* is changed by moving the detector with respect to the primary particle trajectory

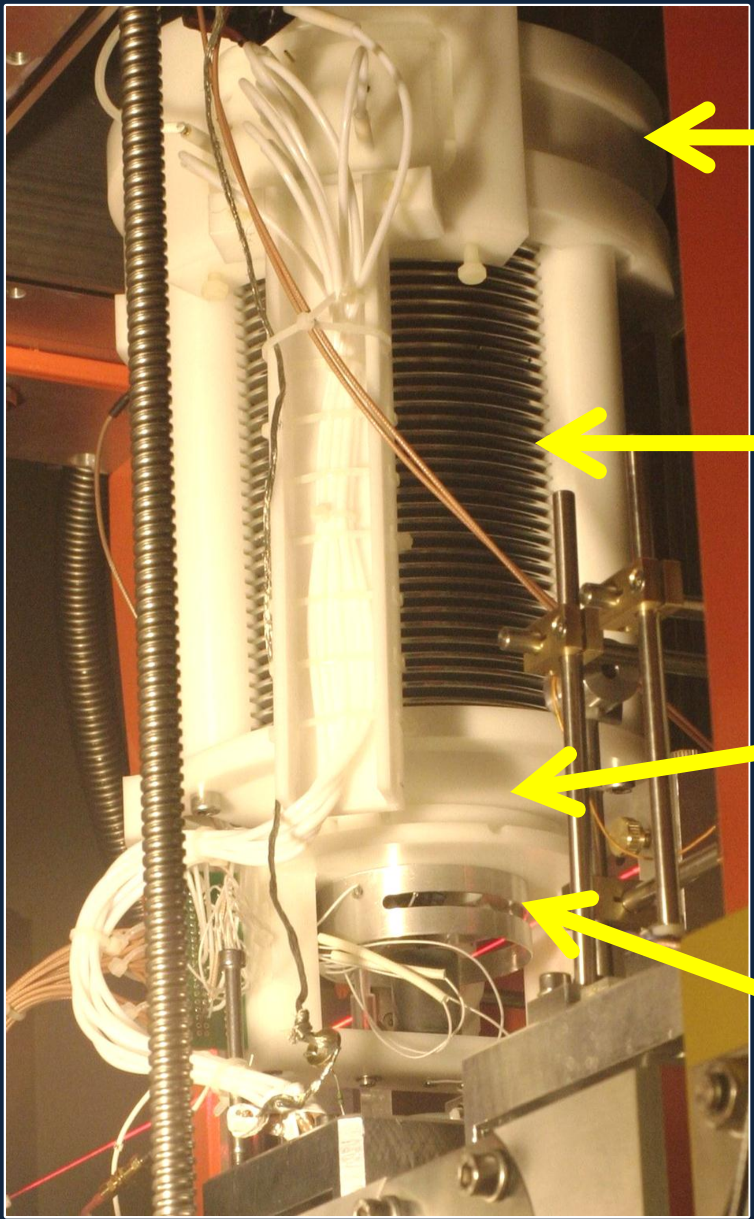
The detection of ionizations is based on single-electron counting

The target volume is delimited by electrodes:
$D = H = 3.7$ mm



The density of the C_3H_8 filling gas is $\rho = 5.47\ \mu g/cm^3$

The track-nanodosimeter of Legnaro National Laboratories



MSAC

drift column

electron transferer

sensitive volume

filled with propane at a pressure of 3 mbar

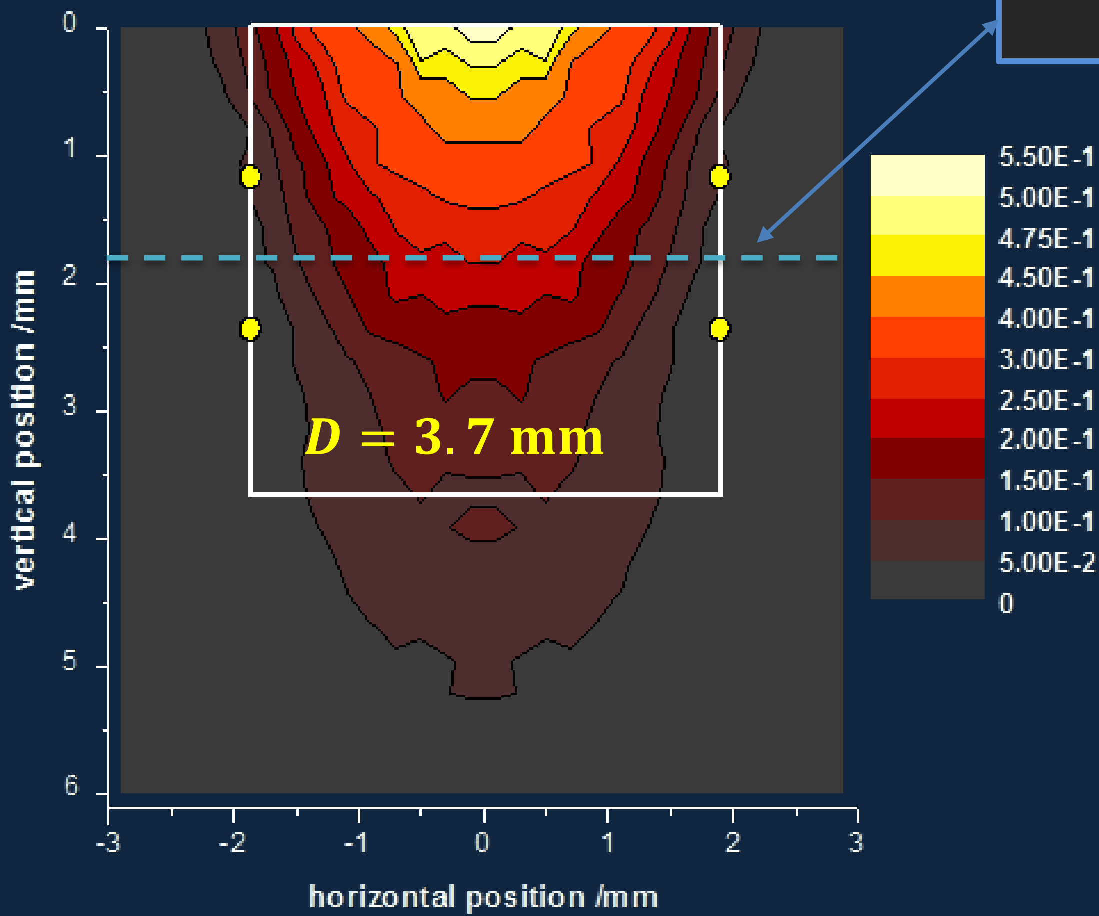
↓

3.7 mm ≅ 2 μg/cm²

↓

20 nm at 1 g/cm³

The detection efficiency $\eta(d, h)$ depends on impact parameter *d* and on vertical position *h*



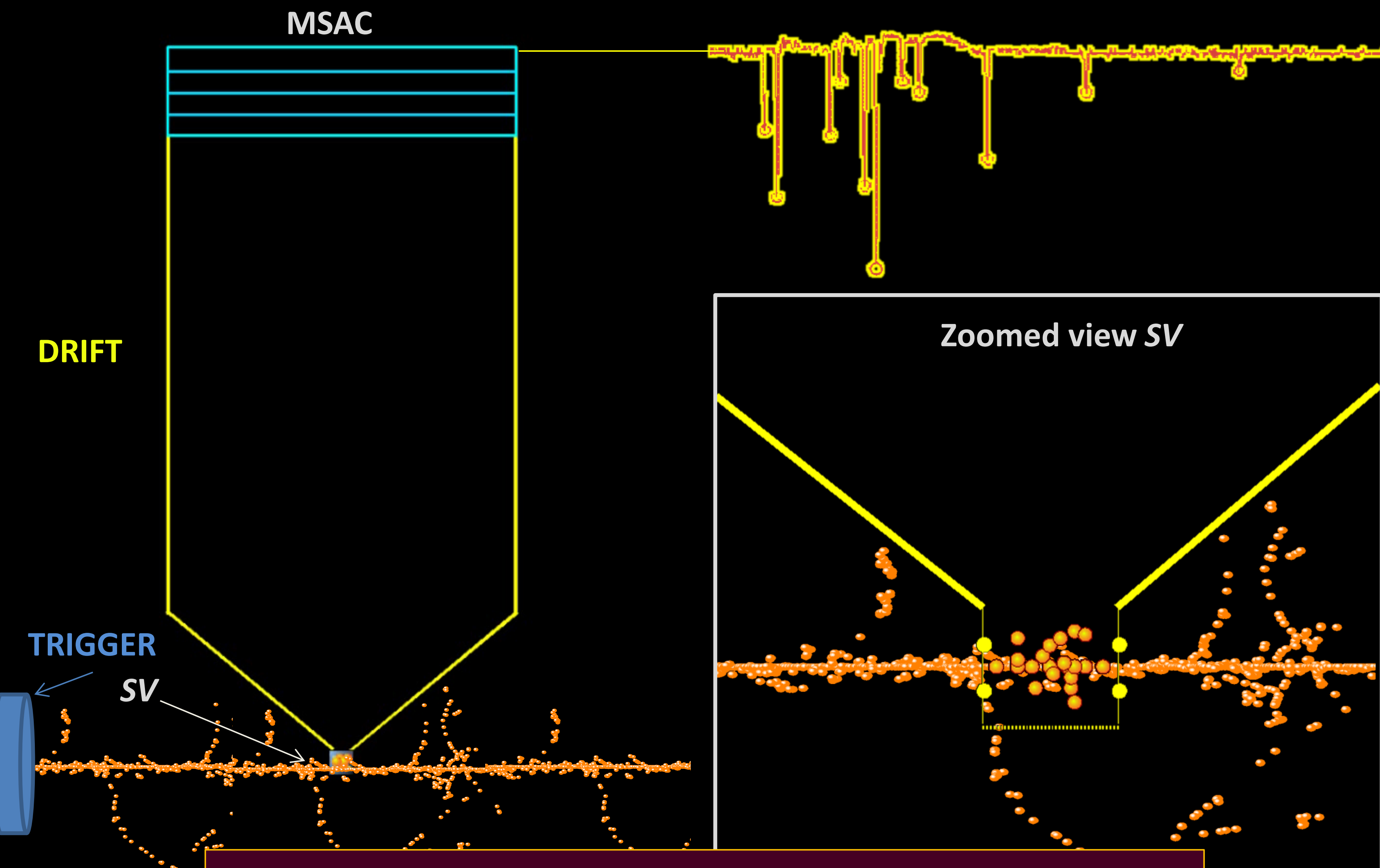
Counting efficiency $\eta \approx 19\%$

$$D\rho \cong 2\ \mu g/cm2$$

$$(D\rho)_{eff} = D\rho \cdot \eta$$

$$(D\rho)_{eff} \cong 0.38\ \mu g/cm^2$$

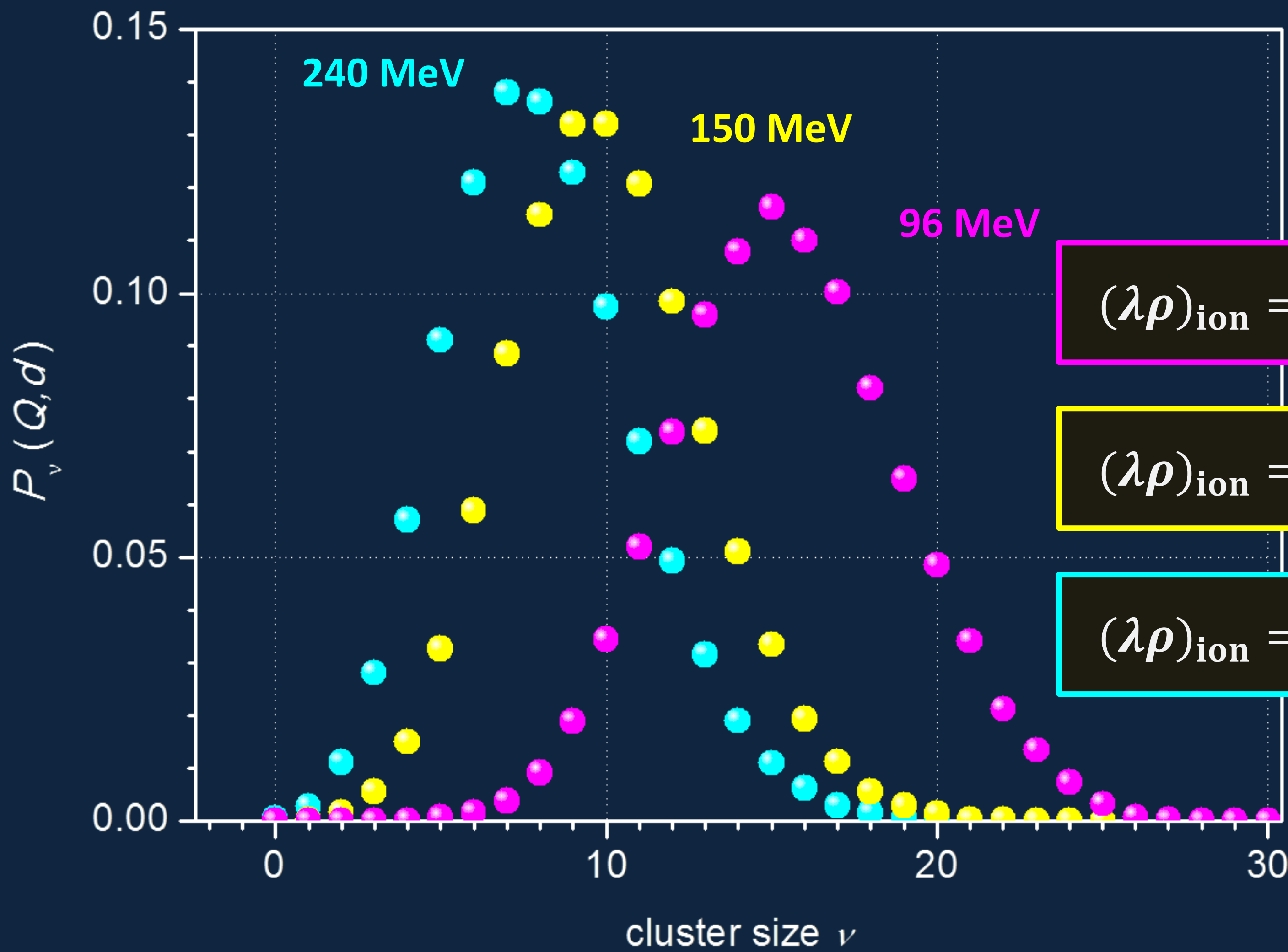
For effect of the counting efficiency η, the target diameter D_W = 20 nm is reduced to an effective target diameter $(D_W)_{eff}$ = 3.8 nm.



The occurrence probability $P_{\nu}(Q,d)$ is measured

ICSD due to 96 MeV, 150 MeV and 240 MeV ^{12}C-ions at Impact Parameter d = 0 mm

λ_{ion} is the mean free path-length for ionizing processes of the primary particles.



$$(\lambda\rho)_{ion} = 0.026 \ \frac{\mu g}{cm^2}$$

$$(\lambda\rho)_{ion} = 0.038 \ \frac{\mu g}{cm^2}$$

$$(\lambda\rho)_{ion} = 0.057 \ \frac{\mu g}{cm^2}$$

Particular Properties of Ionization Cluster Size Distributions

$P_\nu(Q,d)$ is the probability of producing an ionization cluster of size ν

Q = particle type and energy

$M_1(Q,d)$ is the mean ionization cluster size

$$M_1 = \sum_{\nu=1}^{\infty} \nu P_\nu$$

$F_k(Q,d)$ is the cumulative probability of measuring a cluster of size $\nu \geq k$

$$F_k = \sum_{\nu=k}^{\infty} P_\nu \quad \Rightarrow \quad F_2 = \sum_{\nu=2}^{\infty} P_\nu$$

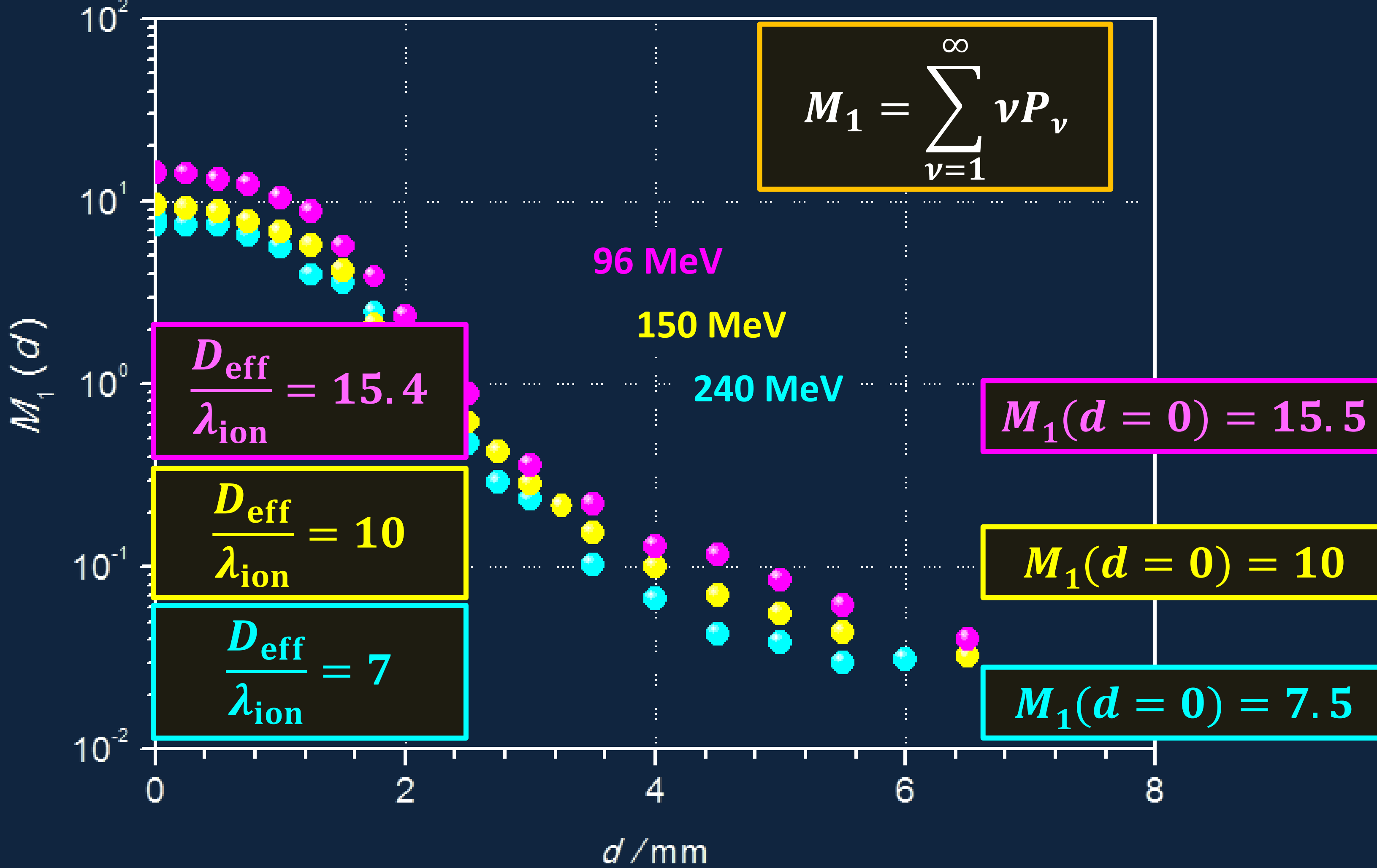
F_2 : probability to initiate at least two ionizations inside the target volume

F_k is interesting from a radiobiological point of view, because an increasing k corresponds to a damage of higher complexity

Mean Ionization-cluster Size M_1 as a Function of Impact Parameter d

D_{eff} is the effective diameter of the sensitive target volume $D_{\text{eff}} \approx 3.8$ nm at $\rho = 1 \frac{\text{g}}{\text{cm}^3}$

λ_{ion} is the corresponding primary-ionization mean free-path length



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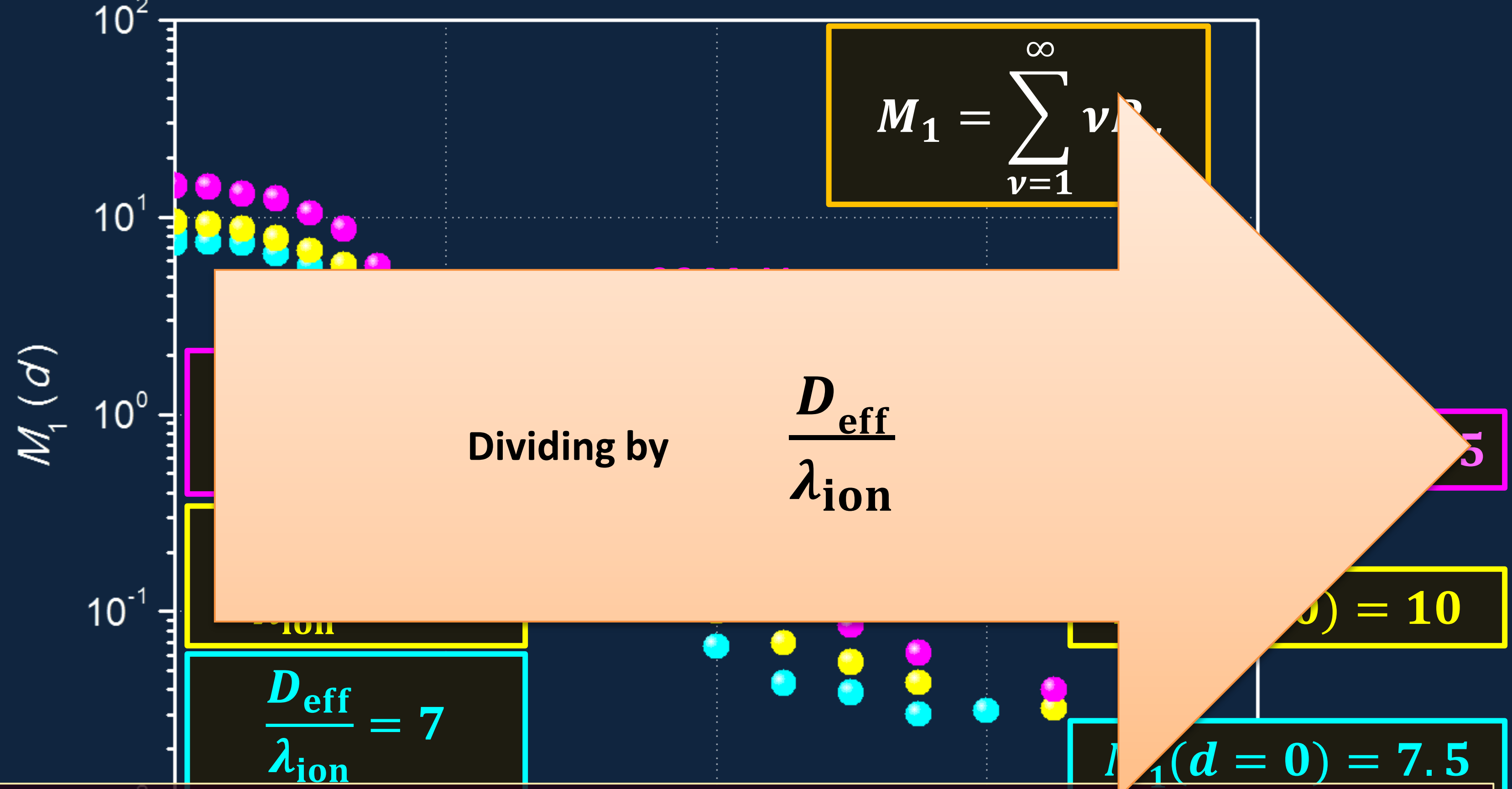
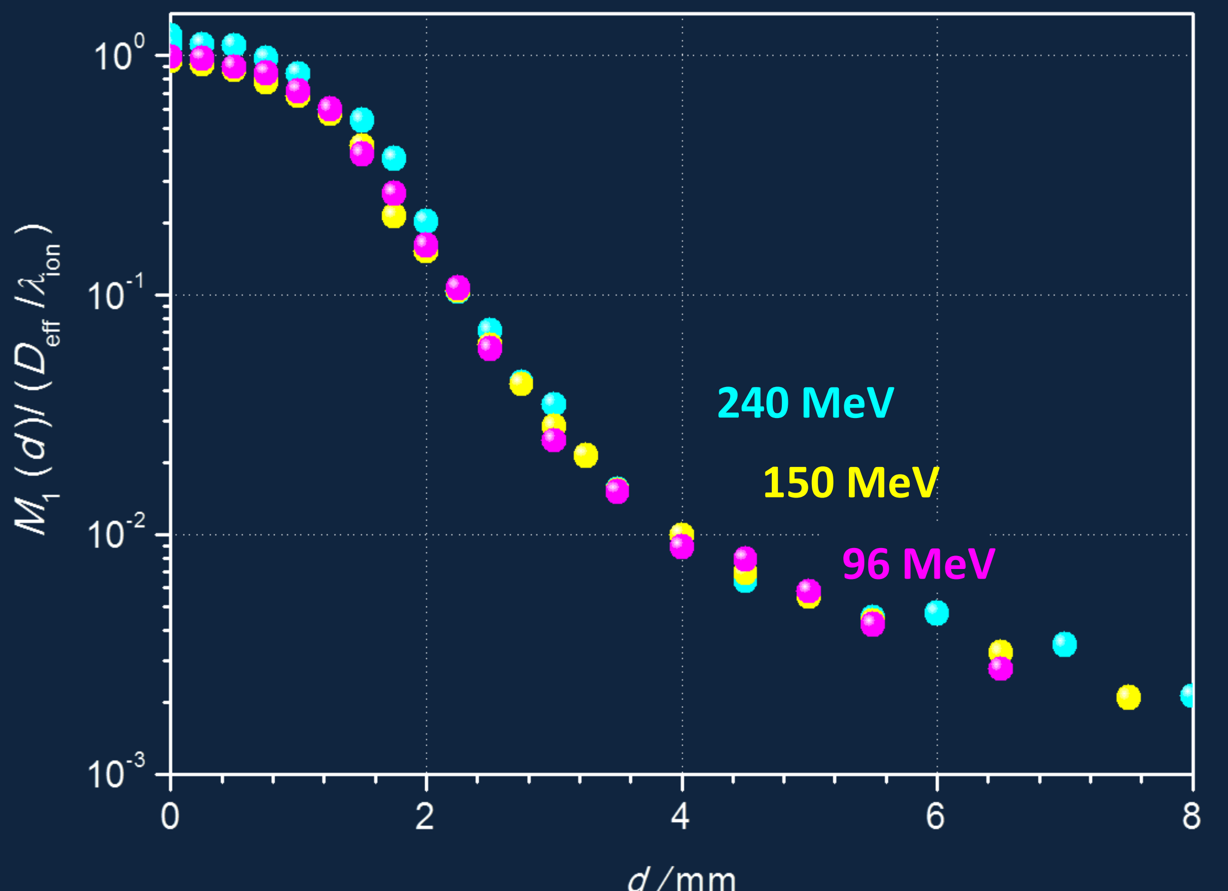


Dividing by $\frac{D_{eff}}{\lambda_{ion}}$

The mean ionization-cluster size M_1 is everywhere proportional to the mean number of primary ionizations D_{eff}/λ_{ion} along D_{eff} ?

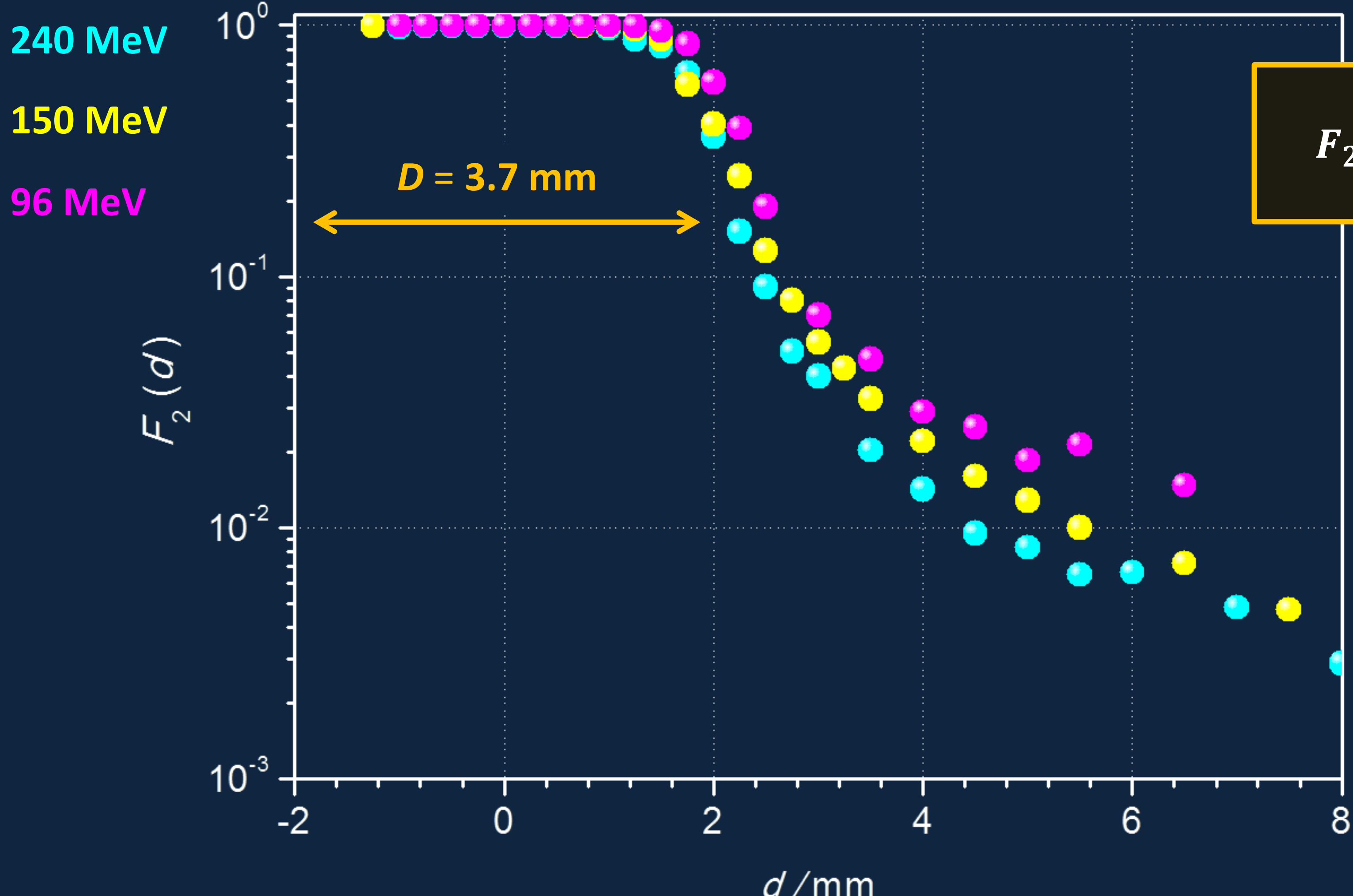
SCALED MEAN IONIZATION-CLUSTER SIZE $M_1/(D_{eff}/\lambda_{ion})$ DUE TO ^{12}C-IONS AS A FUNCTION OF IMPACT PARAMETER *d*



$$M_1 \propto \frac{D_{eff}}{\lambda_{ion}}$$

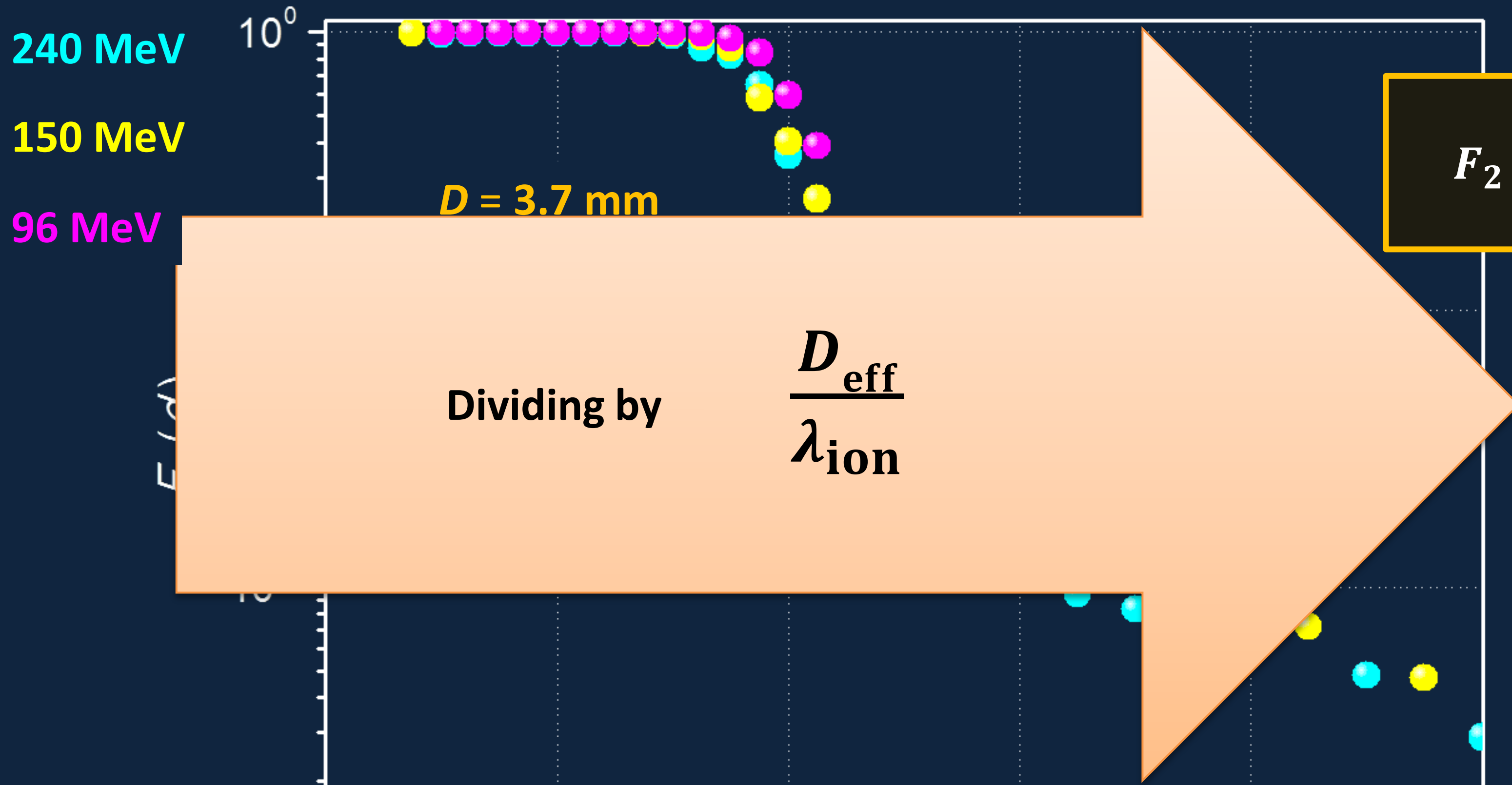
For ^{12}C-ions at 96 MeV, 150 MeV and 240 MeV, the mean ionization-cluster sizes M_1 can be scaled almost perfectly by the mean number of primary ionizations D_{eff}/λ_{ion} along a length D_{eff}

The Sum Distribution F_2 Due to ^{12}C-ions as a Function of Impact Parameter *d*



$$F_2 = \sum_{\nu=2}^{\infty} P_\nu$$

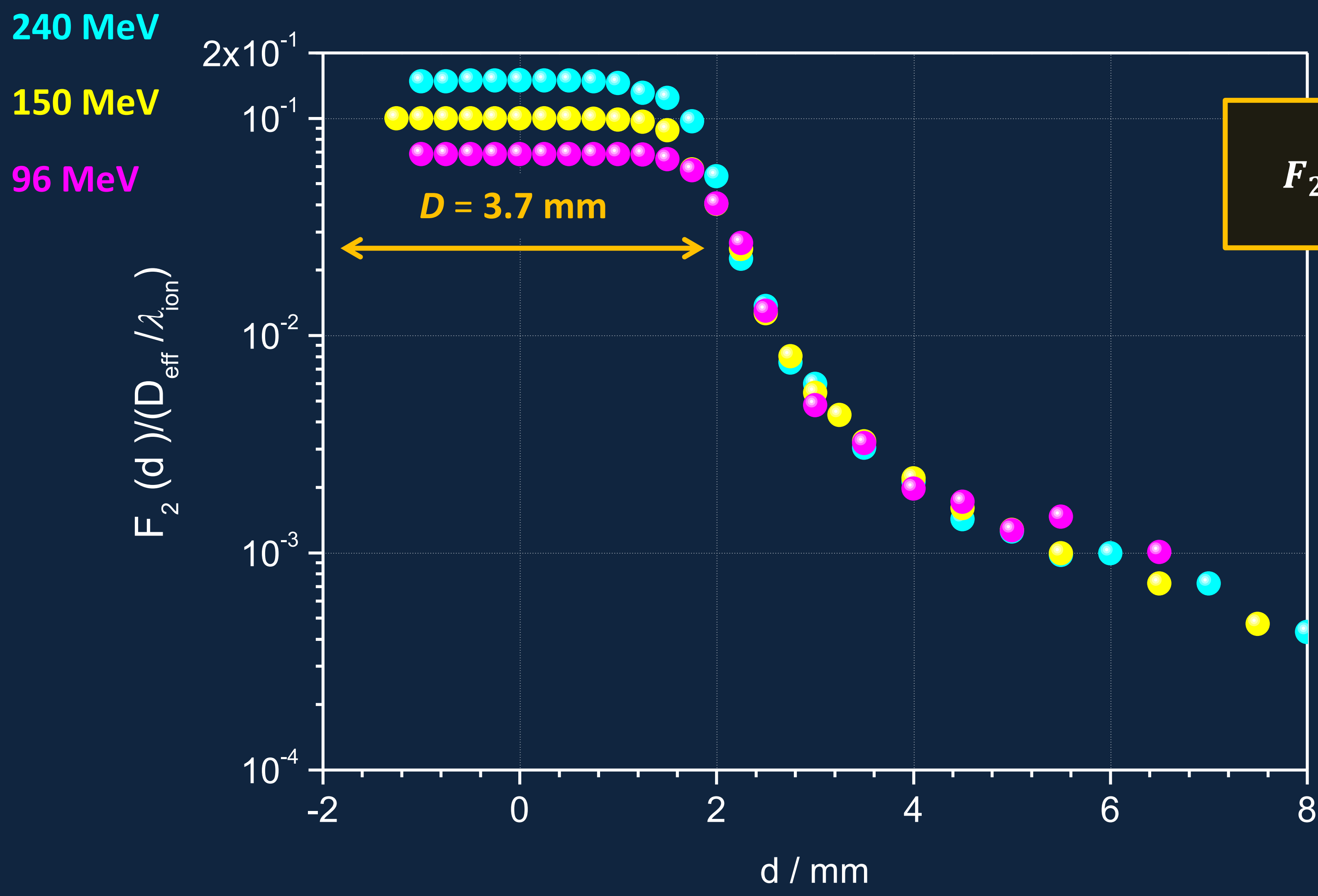
The Sum Distribution F_2 Due to ^{12}C-ions as a Function of Impact Parameter d



$$F_2 = \sum_{\nu=2}^{\infty} P_\nu$$

At small impact parameters, the sum distribution F_2 shows a **saturation effect** whereas at larger impact parameters F_2 also seems to be proportional to the mean number of primary ionizations $D_{\mathrm{eff}}/\lambda_{\mathrm{ion}}$ along a travelling length D_{eff}

Scaled Sum Distribution $F_2/(D/\lambda_{ion})$ as a function of impact parameter d



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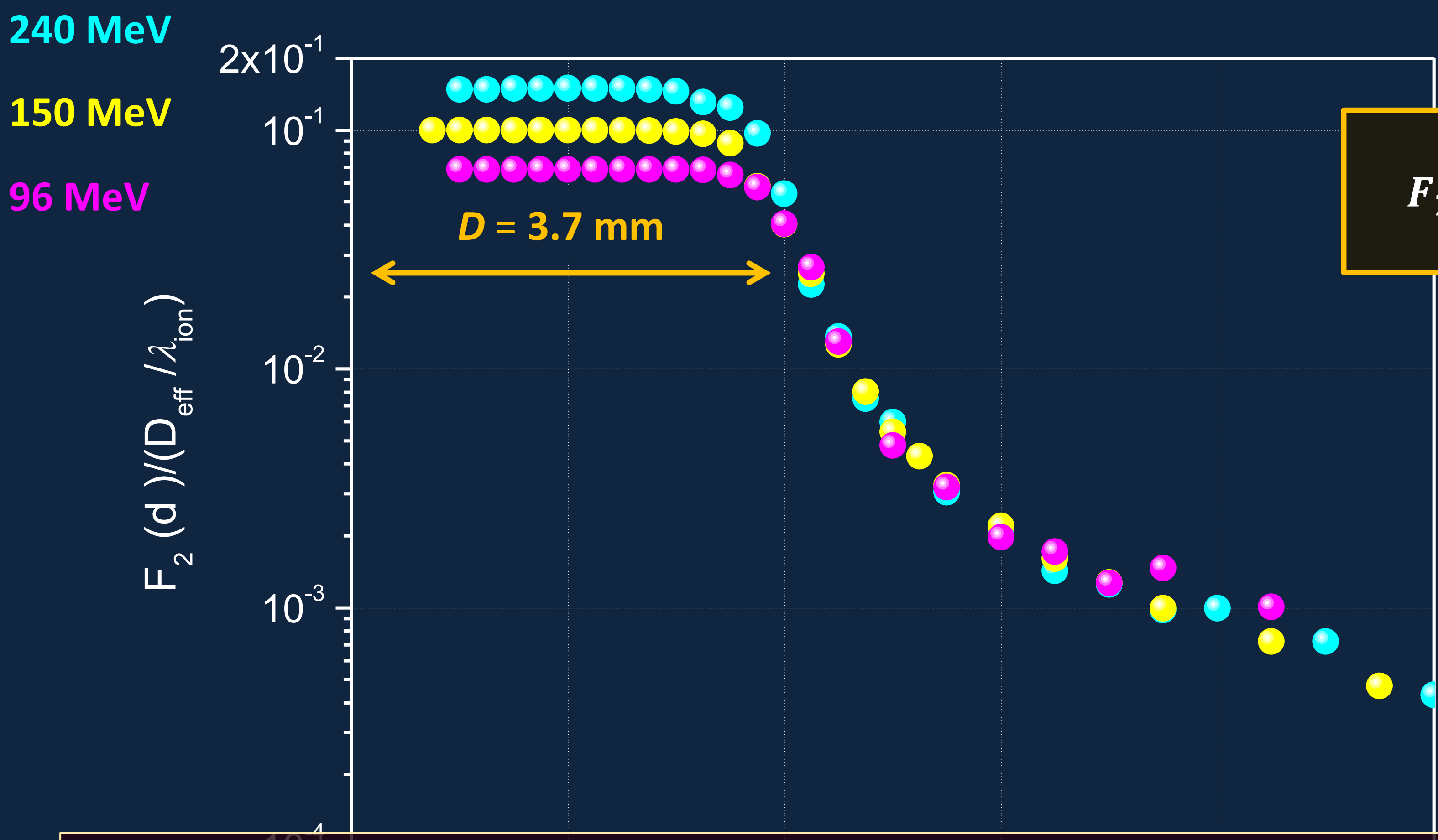


$$F_2 = \sum_{\nu=2}^{\infty} P_\nu$$

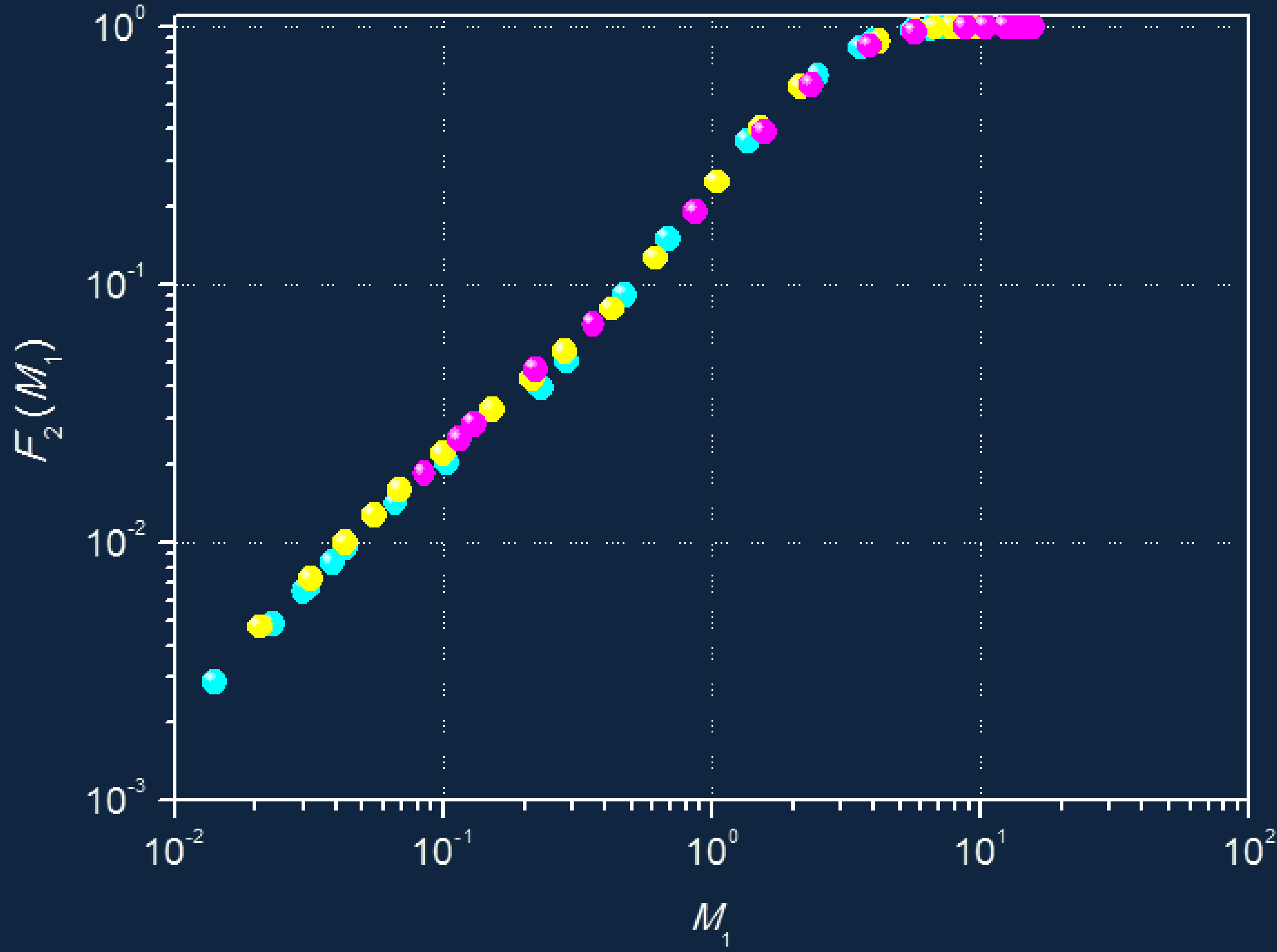
For [12]C-ions at 96 MeV, 150 MeV and 240 MeV, the sum distribution F_2 can be scaled at larger impact parameters almost perfectly by the mean number of primary ionizations D_{eff}/λ_{ion} along a travelling length D_{eff}

The Sum Distribution F_2 Due to ^{12}C-ions as a Function of mean cluster size M_1

240 MeV

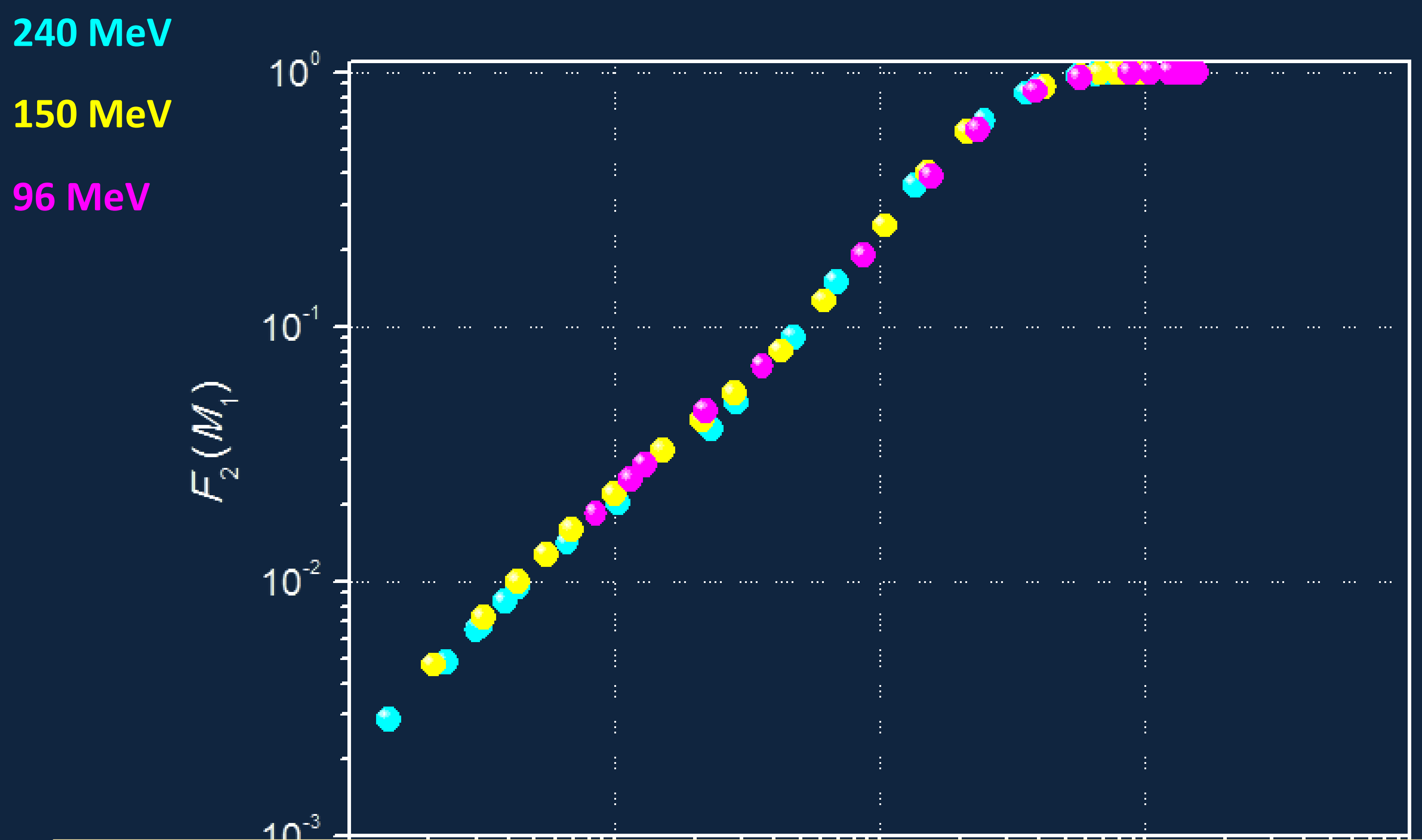
150 MeV

96 MeV



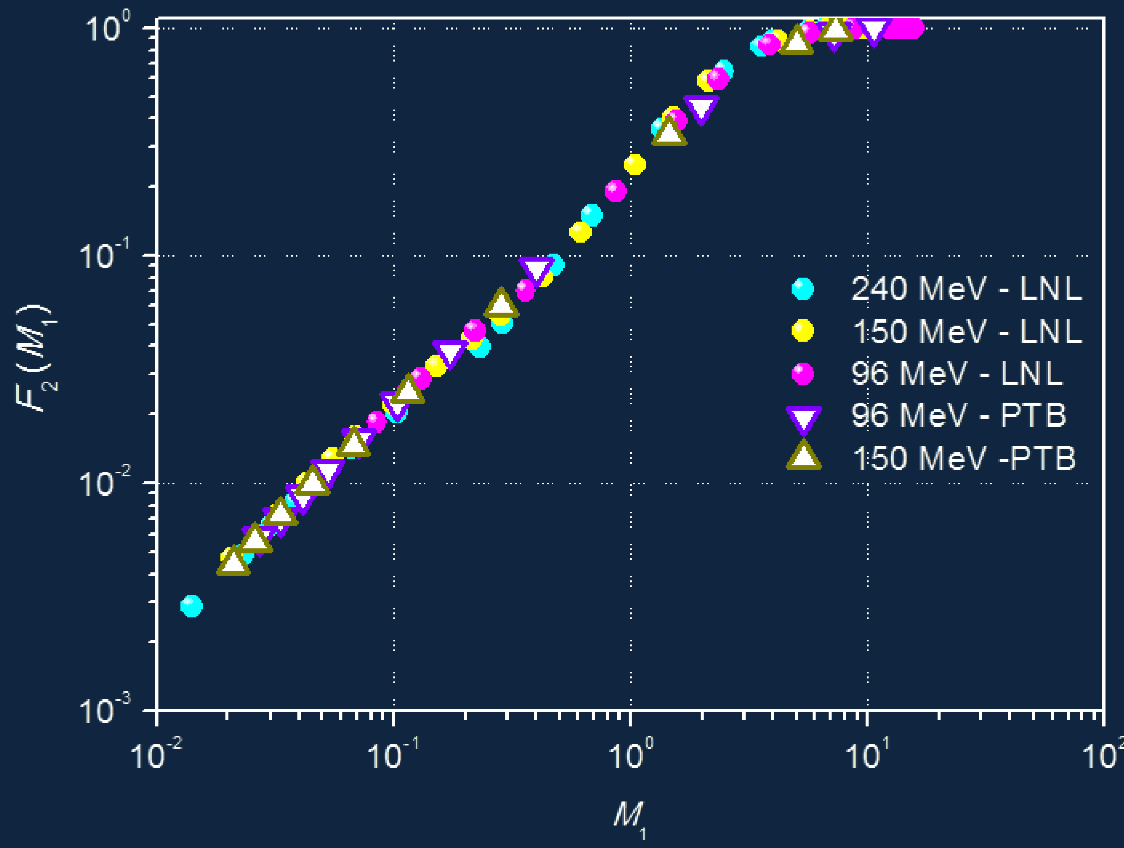
Data presented at MICROS 2013

The Sum Distribution F_2 Due to ^{12}C-ions as a Function of mean cluster size M_1



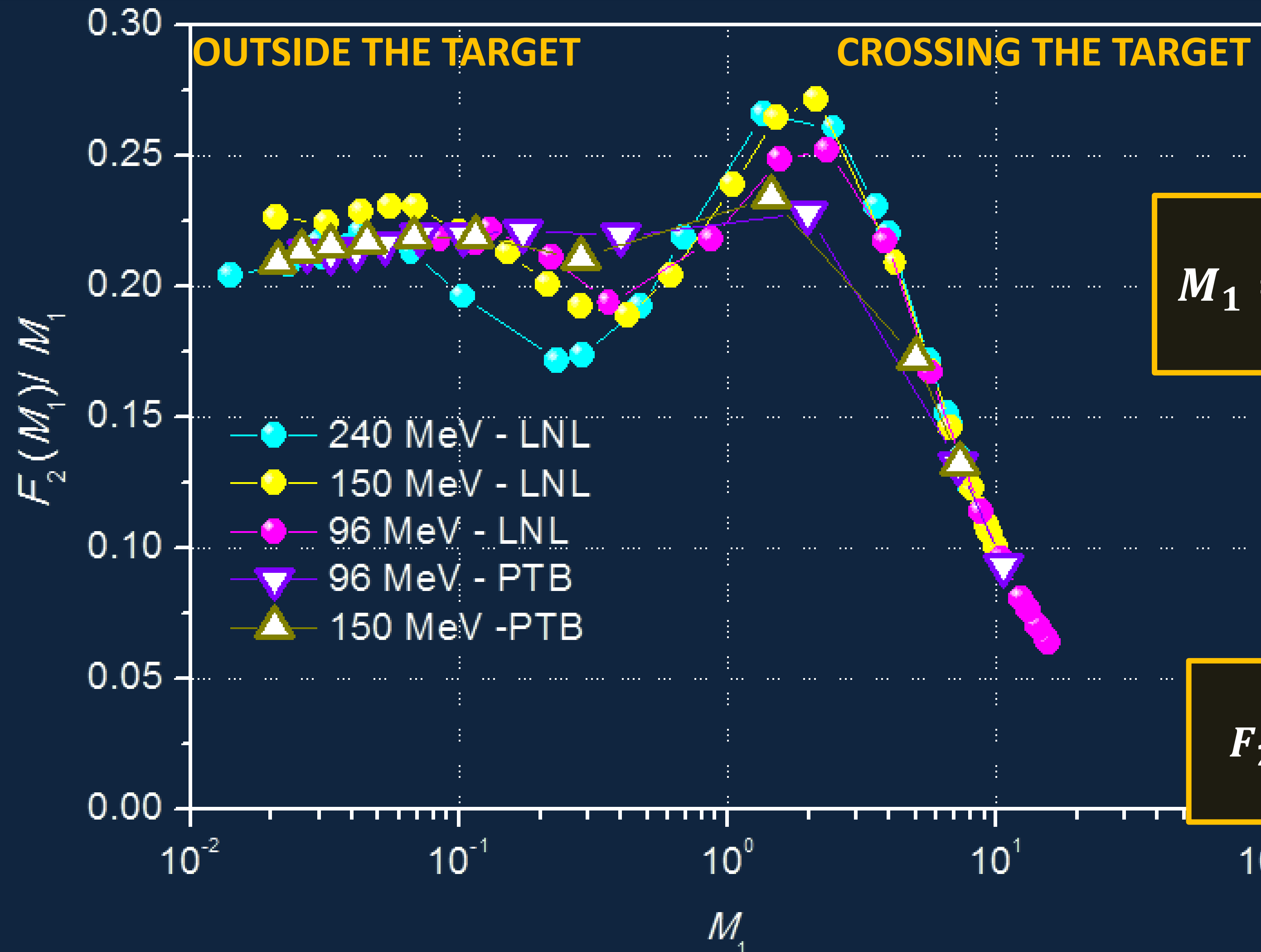
For ^{12}C-ions at 96 MeV, 150 MeV and 240 MeV, the sum distribution F_2 versus M_1 forms an almost perfect universal curve, and shows a saturation effect like **radio-biological cross sections** as a function of *LET*

The Sum Distribution F_2 Due to ^{12}C-ions as a Function of mean cluster size M_1



For ^{12}C-ions at 96 MeV, 150 MeV and 240 MeV, the sum distribution F_2 versus M_1 forms an almost perfect universal curve, and shows a saturation effect like radio-biological cross sections as a function of *LET*

Scaled Sum Distribution F_2/M_1 Due to ^{12}C-ions as a Function of Mean Ionization-cluster Size M_1

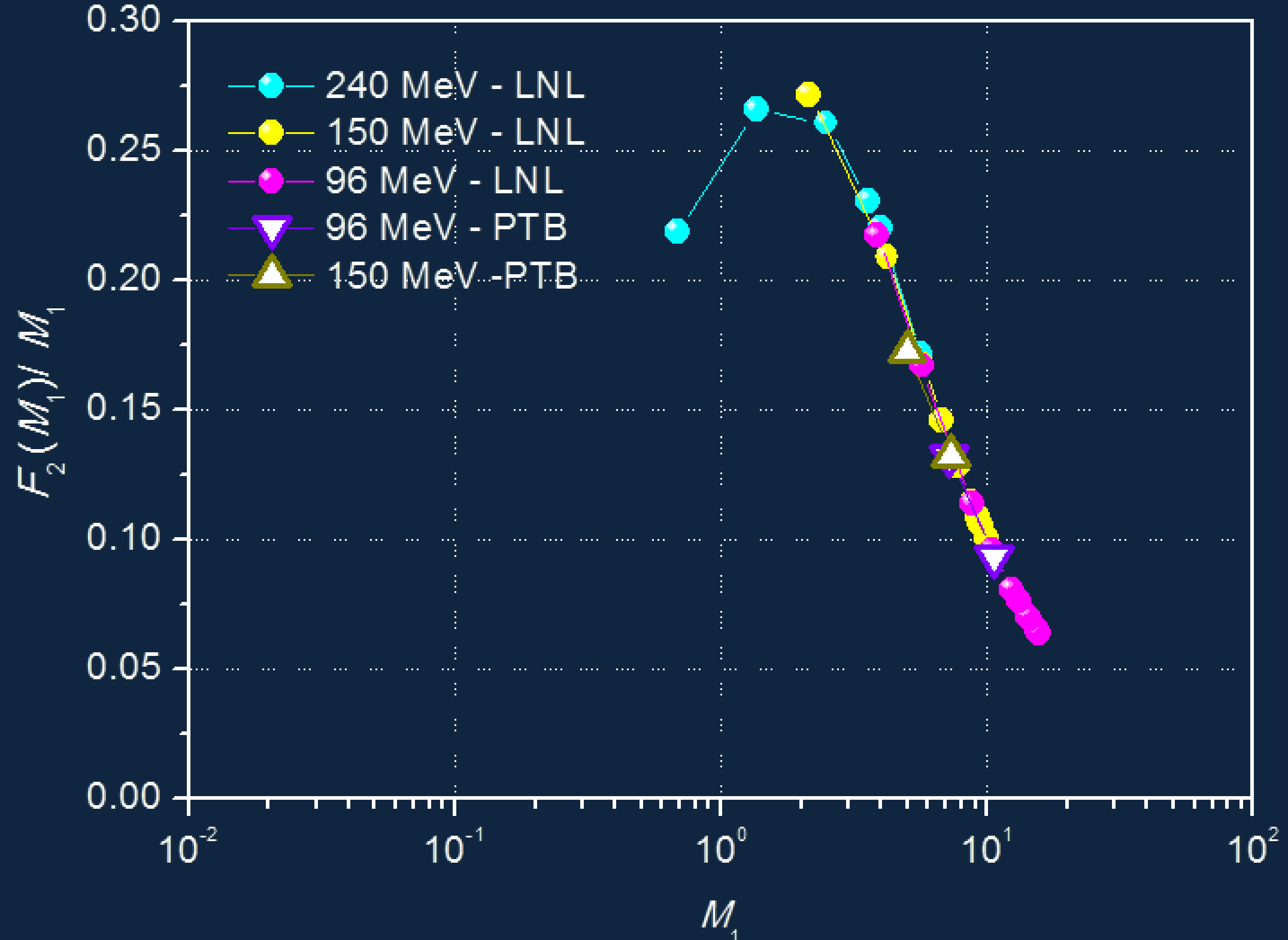


$$M_1 = \sum_{\nu=1}^{\infty} \nu P(\nu)$$

$$F_2 = \sum_{\nu=2}^{\infty} P(\nu)$$

The ratio F_2/M_1 behaves almost as a unique function of M_1

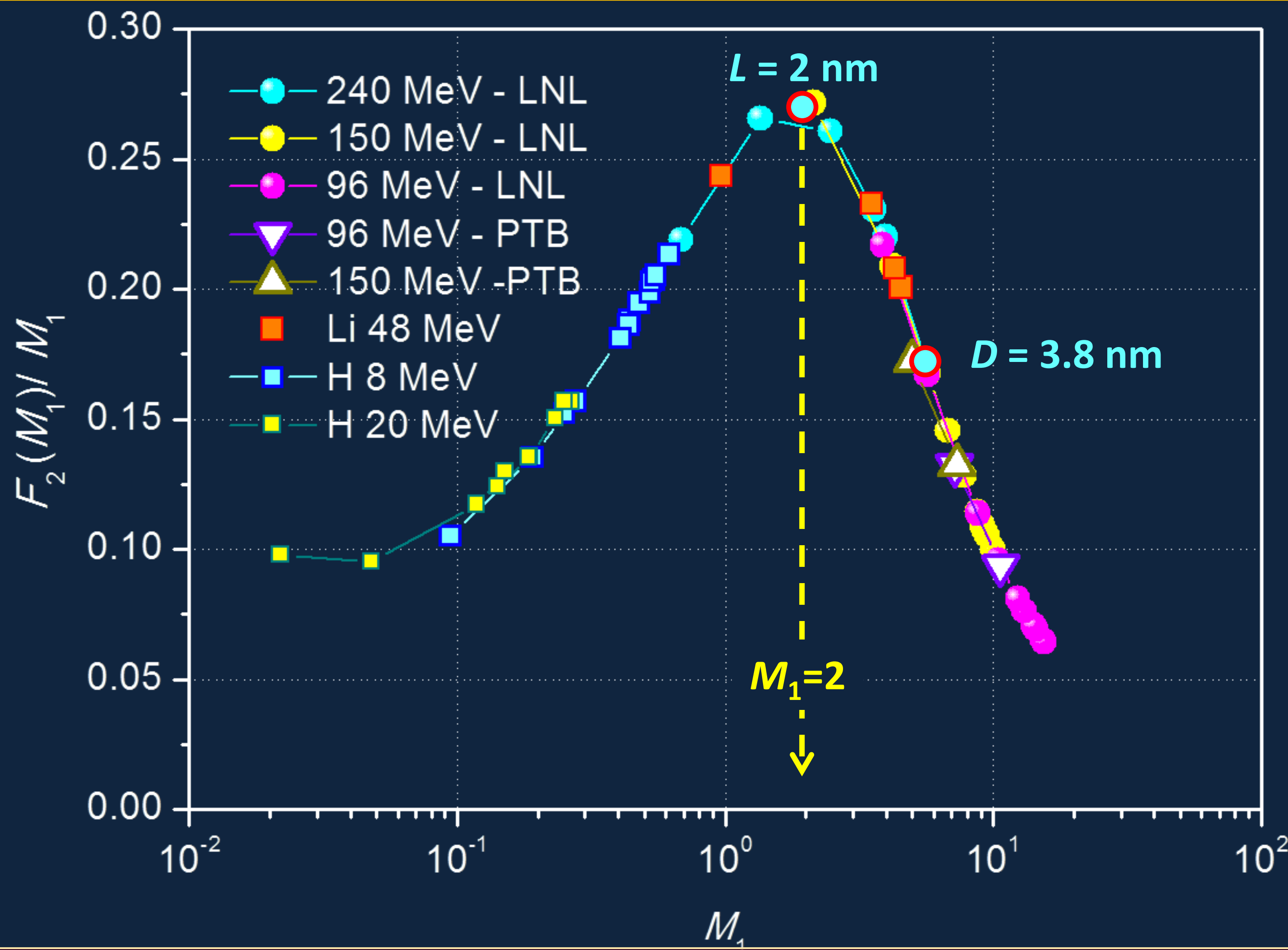
Scaled Sum Distribution F_2/M_1 due to ^{12}C-ions crossing the target volume



The ratio F_2/M_1 behaves as a unique function of M_1

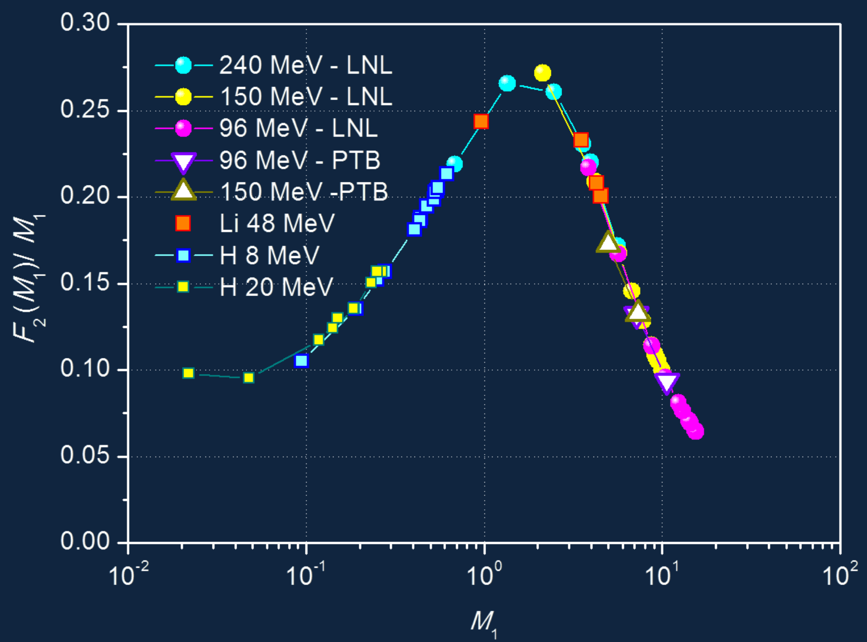
PTB ion-counter data: courtesy of G.Hilgers (private communication).

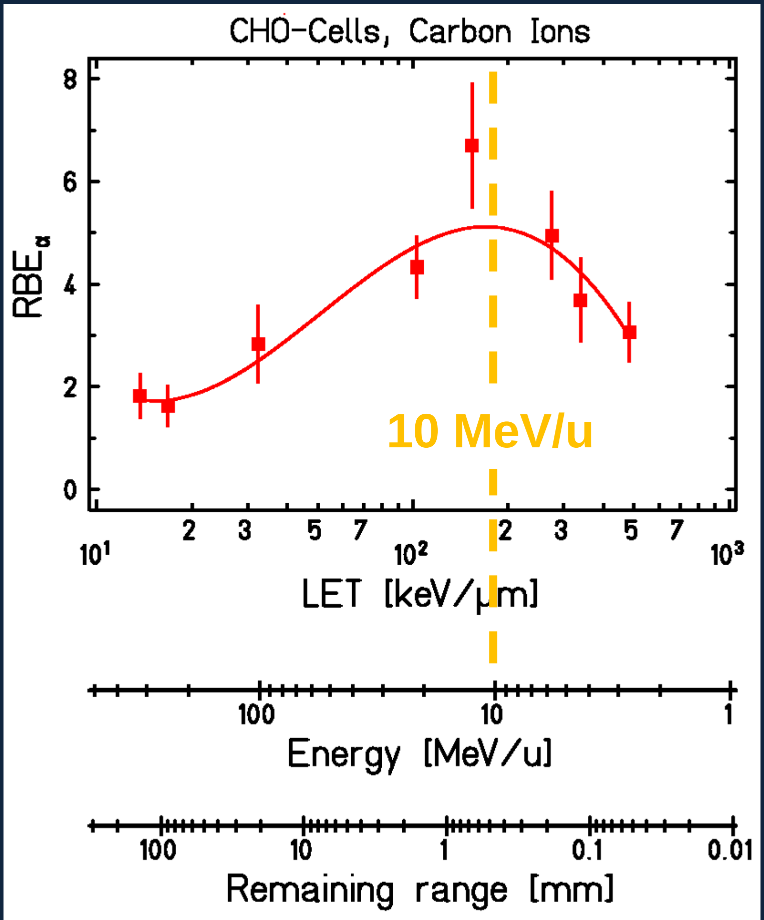
The ratio F_k/M_1 behaves as a unique function of M_1



The ratio F_2/M_1 behaves as a function of M_1 like the RBE$_\alpha$ as a function of *LET*

The ratio F_k/M_1 versus M_1 mimics the behaviour of RBE_α as a function of LET

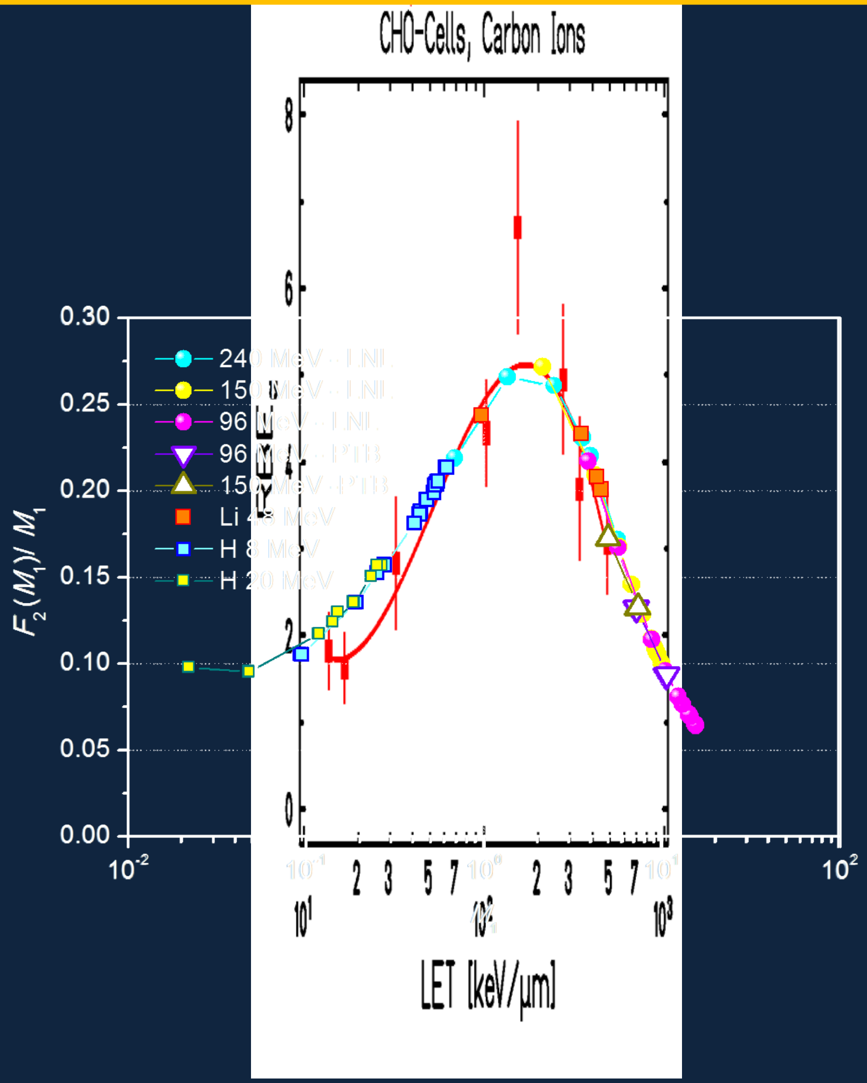


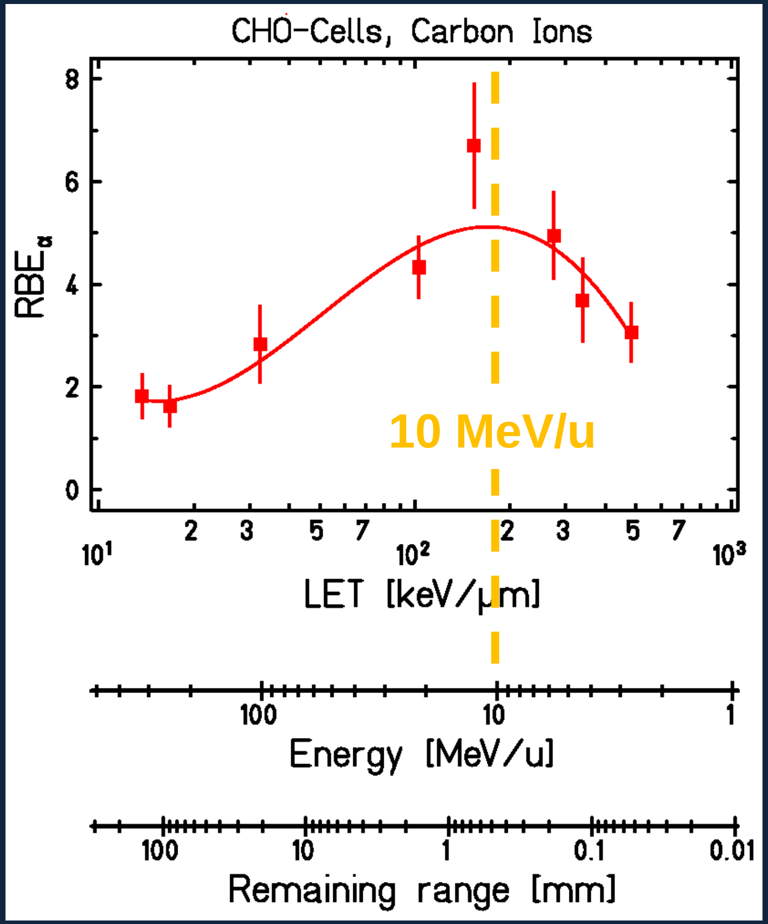


Weyrather et al. IJRB 1999
PTCOG Educational Workshop, 2010

The ratio F_2/M_1 behaves as a function of M_1 like the RBE_α as a function of *LET*

The ratio F_2/M_1 versus M_1 mimics the behaviour of RBE_α





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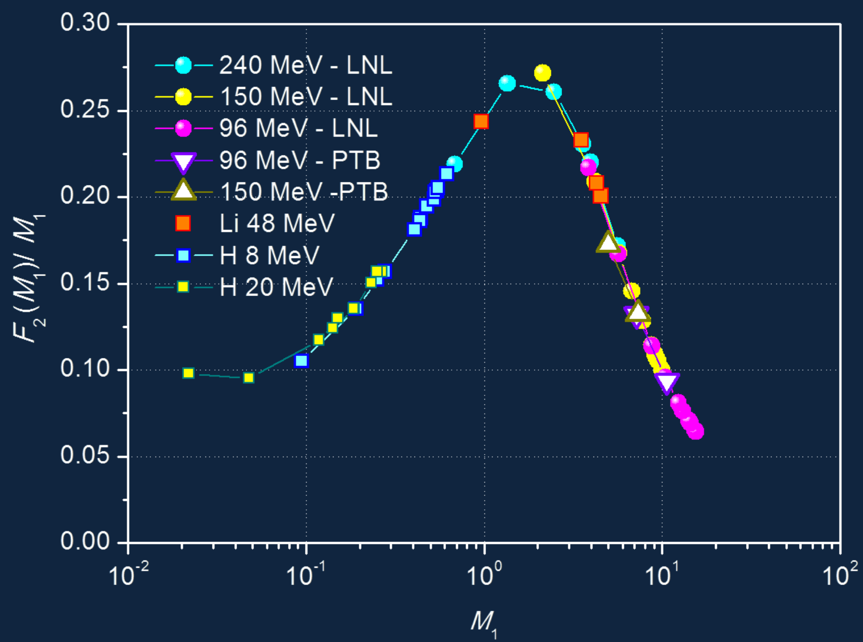
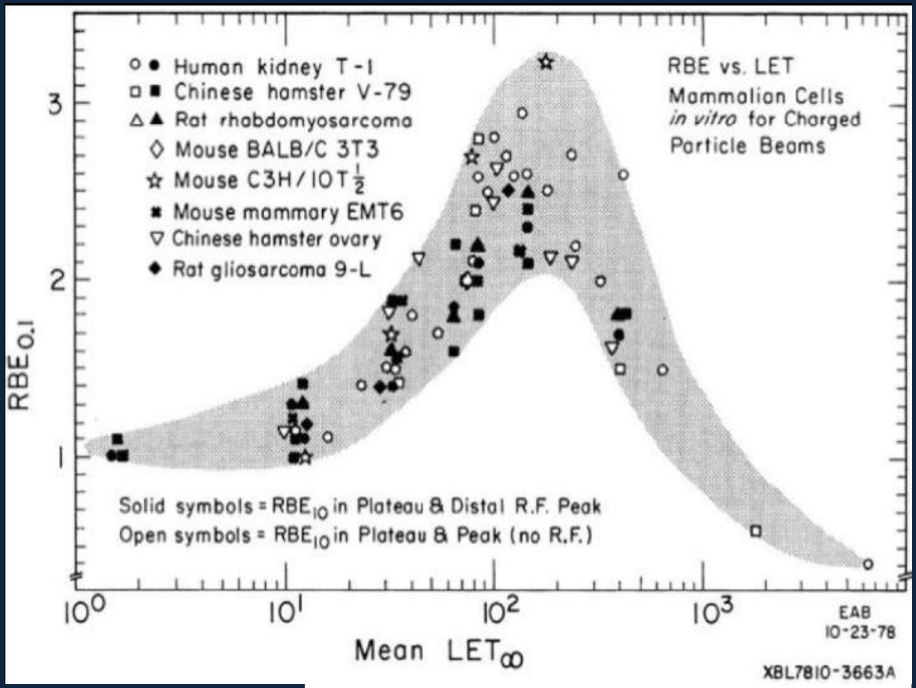
The ratio F_2/M_1 behaves as a function of M_1 like the RBE_α as a function of *LET*

The ratio F_2/M_1 versus M_1 mimics the behaviour of RBE as a function of LET

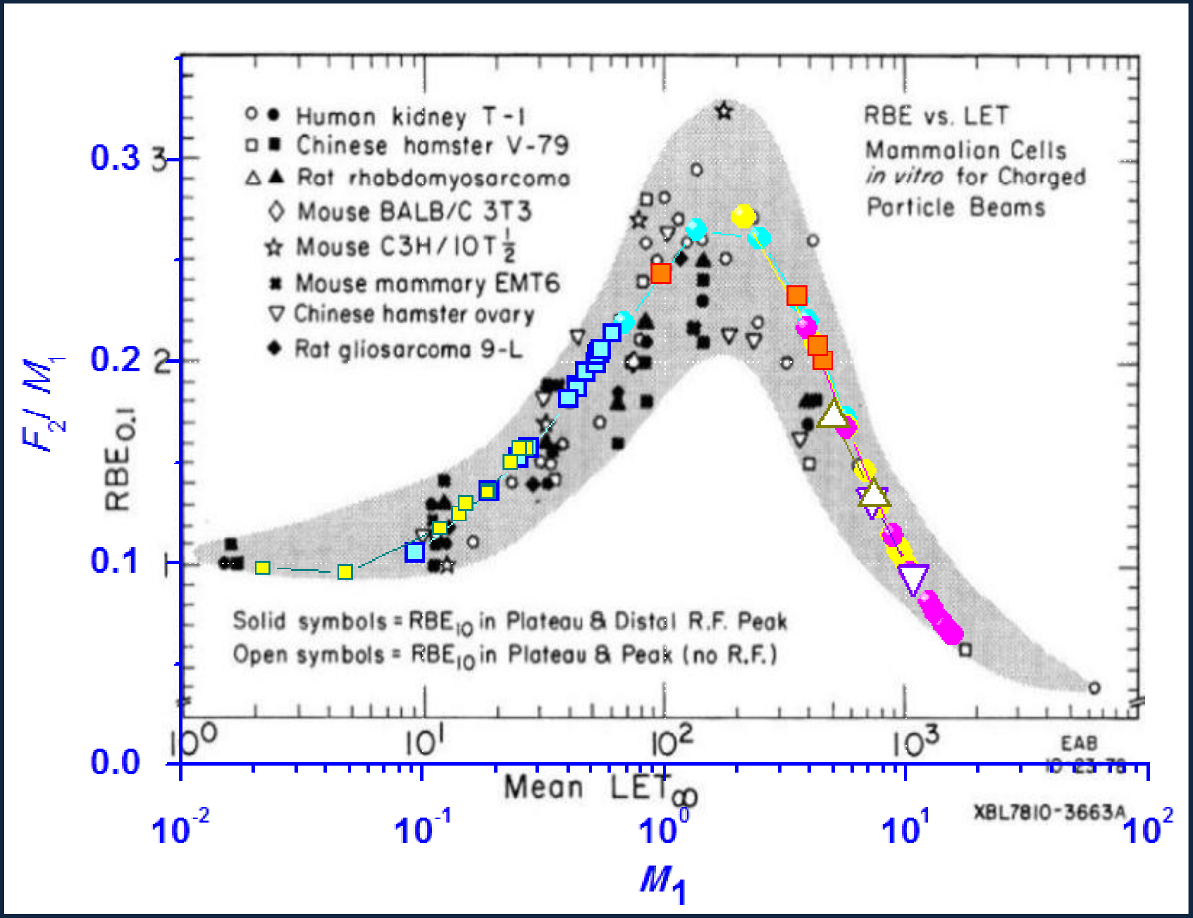




E. A. Blakely et al, Adv. Radiat. Biol. 11: 295- 389 (1984)

M_1 reflects the ionization density D_{eff}/λ_{ion} and is measurable

The ratio F_2/M_1 versus M_1 mimics the behaviour of RBE as a function of LET



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