WP2: Nanodosimetry

PTB, NCBJ, PoliMi, REG(INFN)

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On behalf of the WP2 collaboration:

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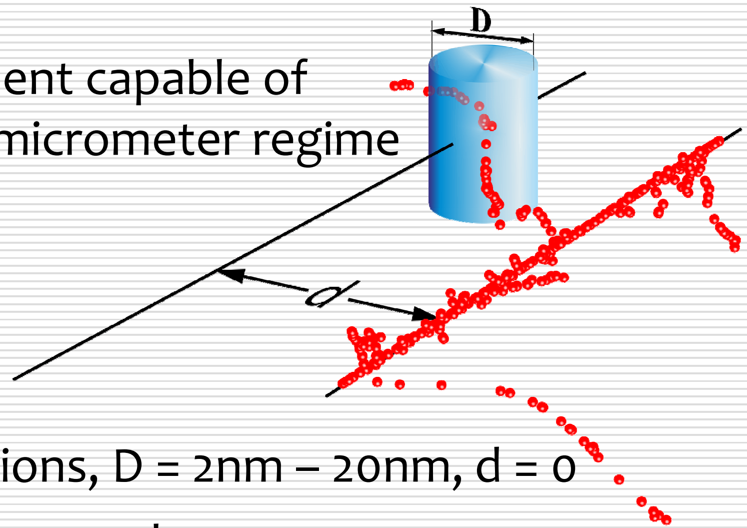
WP2: Nanodosimetry (PTB, NCBJ, PoliMi, REG(INFN))

Measurement and simulation of track structures

Establish correlation of nanodosimetric track structure parameters measured on different length scales

Investigate feasibility of developing an instrument capable of measuring track structure from nanometer to micrometer regime



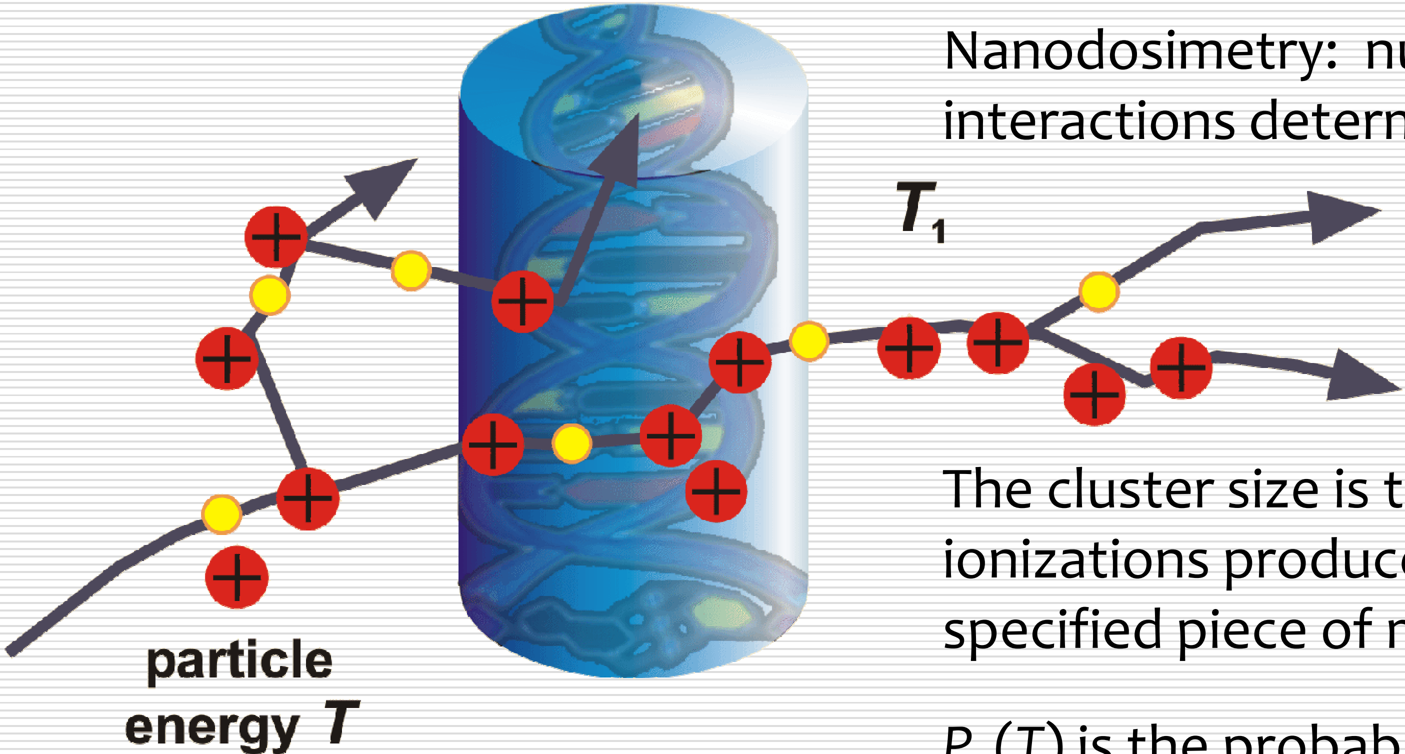
Involved:

Three nanodosimeters:

Jet Counter (NCBJ):	N_2 (pulsed), e^-, ions, D = 2nm – 20nm, d = 0
StarTrack Counter (INFN):	C_3H_8, ions, D = 20nm, d ≠ 0
Ion Counter (PTB):	N_2, C_3H_8, … , ions, D = 1nm – 5nm, d ≠ 0

Si-micro-telescope (PoliMi)

Nanodosimetric quantities



Nanodosimetry: number of interactions determines DNA-damage

The cluster size is the number ν of ionizations produced by a particle in a specified piece of matter.

$P_\nu(T)$ is the probability of producing an ionization cluster of size ν.

$M_1(T) = \sum_{\nu=0}^{\infty} \nu \cdot P_\nu(T)$ is the mean ionization cluster size

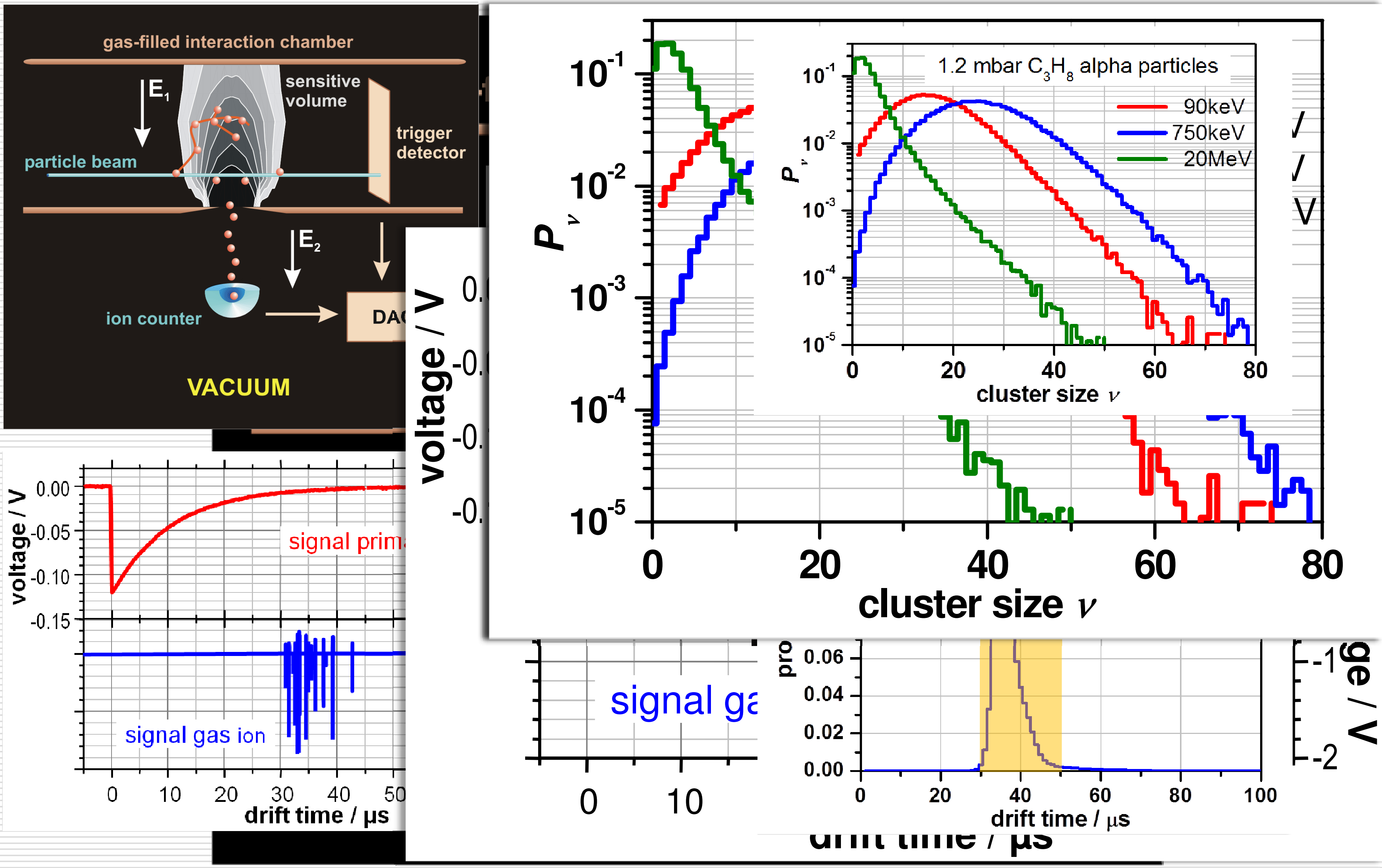
Experimental aspects

Goal: experimentally access the ionization cluster size distribution of ionizing particles in nanometric water targets

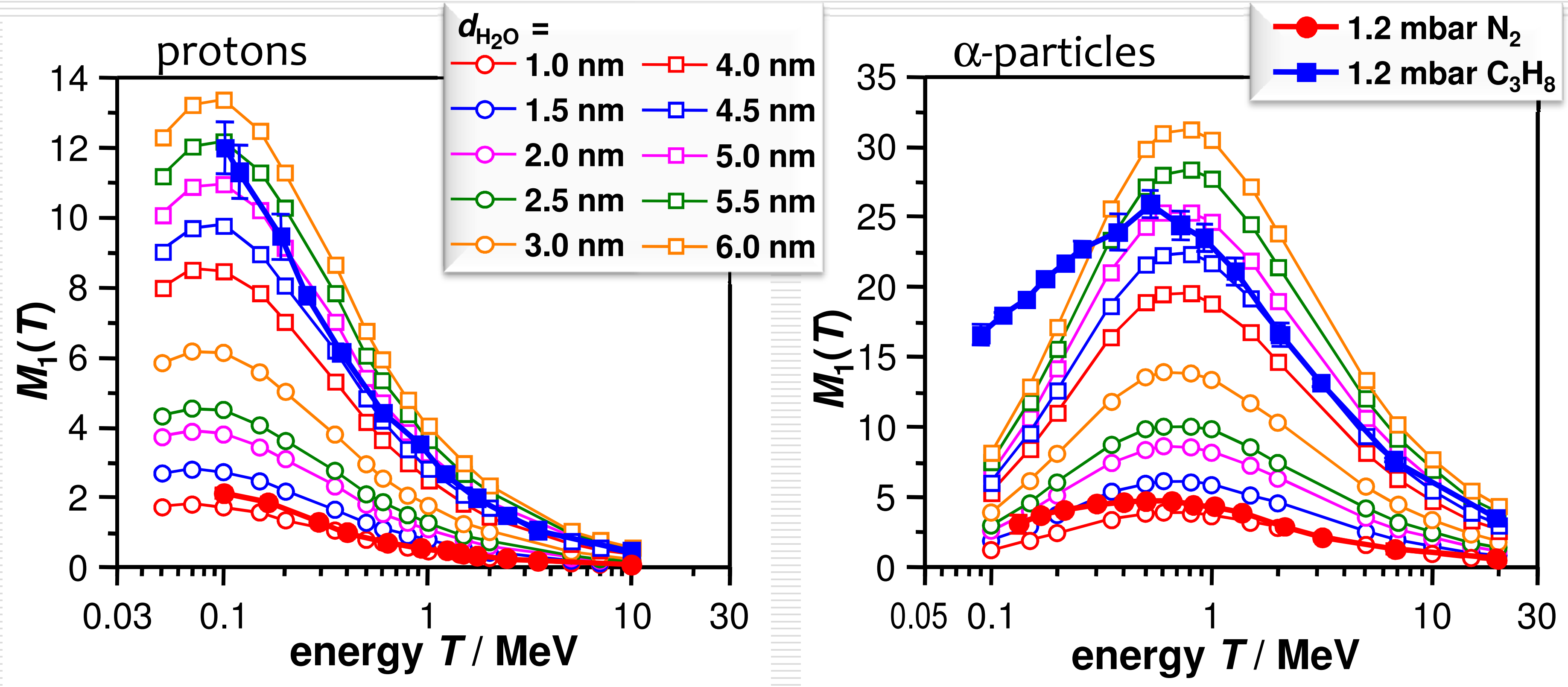
How : count all ionizations produced by a single ionizing particle in a nanometric volume element of water for a large number of ionizing particles

- replace liquid water cylinder (DNA-segment) with low pressure gas volume; **density: 1 g/cm³ → 1 µg/cm³** ; **dimension: nm → mm**
- drift the ionized gas molecules away from particle track, separate them in time and extract them from the interaction volume
- count the collected ionized gas molecules in correlation to the ionizing particle;
- repeat this over and over again …

Experimental setup



Effective size: Nanodosimeter sensitive volume and liquid water cylinder diameter



$M_1(T)$: 1.2 mbar N_2 (exp.)	→	1.0 nm H_2O (sim.)
1.2 mbar C_3H_8 (exp.)	→	4.5 nm H_2O (sim.)
Change of target gas (+pressure)	**→**	**adjusts water cylinder diameter**

Scaling of cluster size distributions

mean cluster size: $$M_1(T) \approx \frac{D}{\lambda} = \frac{D\rho}{\lambda\rho}$$

cluster size distributions are comparable when:

$$M_1(T)_{material\,1} = M_1(T)_{material\,2}$$

☞ $$\frac{(D\rho)_{material\,1}}{(D\rho)_{material\,2}} = \frac{(\lambda\rho)_{material\,1}}{(\lambda\rho)_{material\,2}}$$

with: D = diameter of sensitive volume
ρ = density
λ = mean free path for ionization

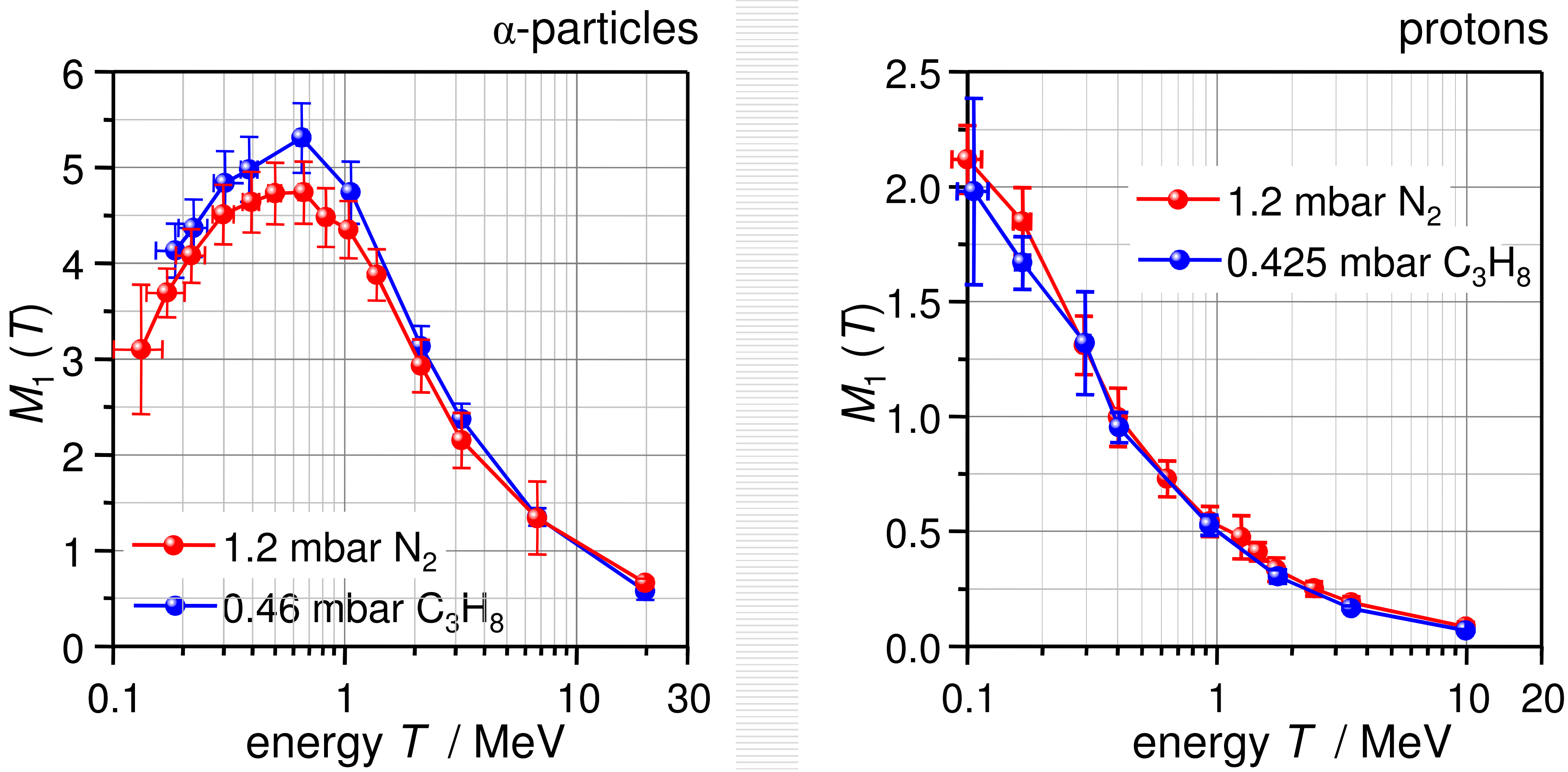
From stopping power and mean ionization energy:

☞ 1.2mbar N_2 / 0.31mbar C_3H_8

Difference in extraction efficiency of ions from sensitive volume:

☞ 1.2mbar N_2 / 0.44mbar C_3H_8

Scaling of cluster size distributions



Task 2.1: Multi-scale measurement of particle track characteristics as function of distance between track and target (REG(INFN), PTB)

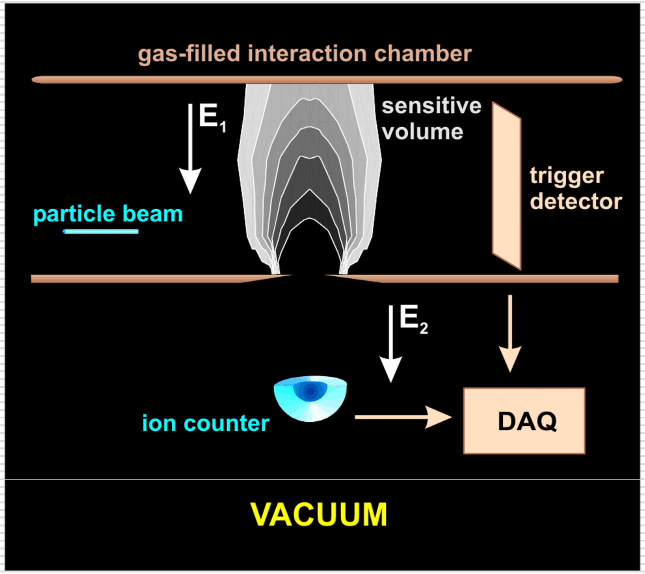
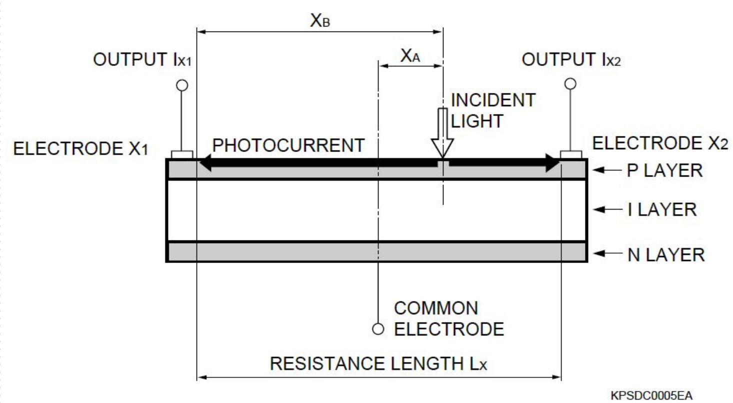
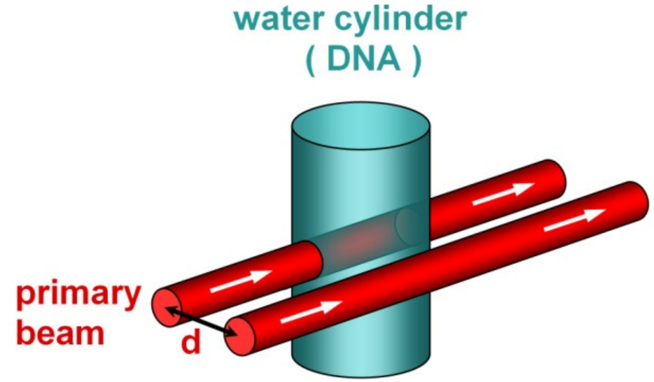


Figure 1-1 PSD sectional view

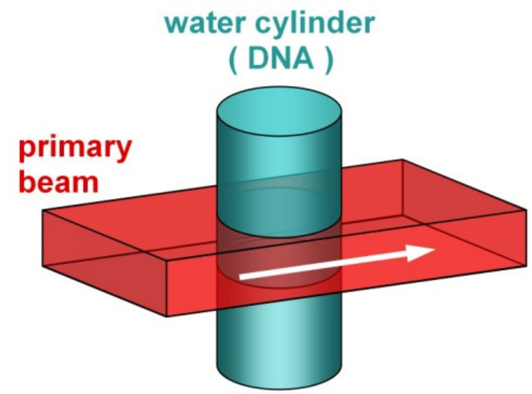


$$X_A = 0{,}5\, L_X \,(\, I_{X_1} - I_{X_2}\,) \,/\, (\, I_{X_1} + I_{X_2}\,)$$

Narrow beam geometry with primary beam offset d:



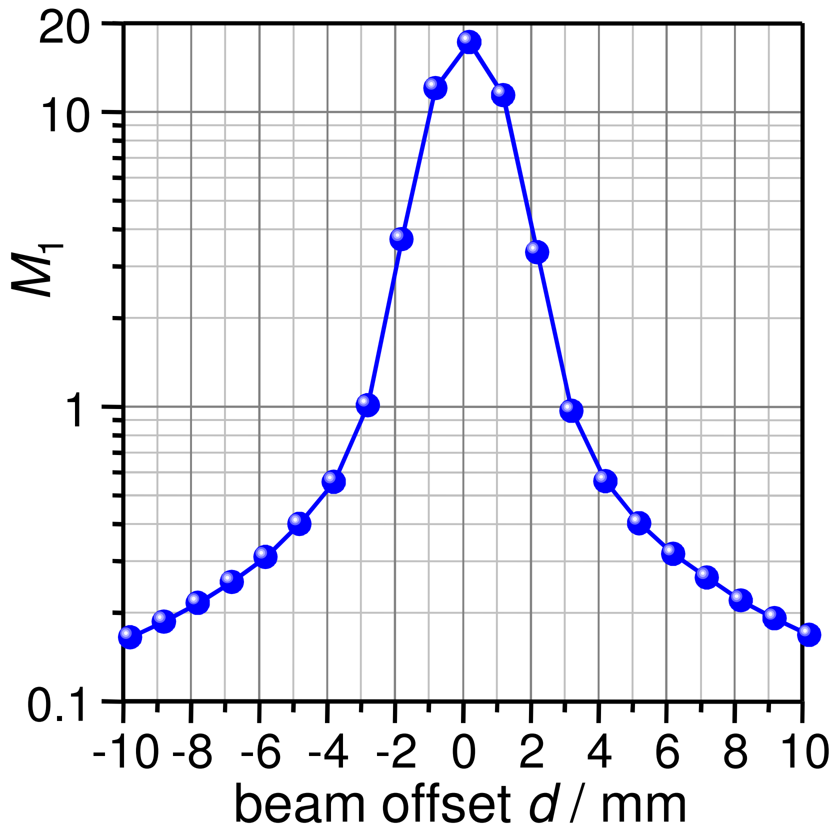
Broad beam geometry:



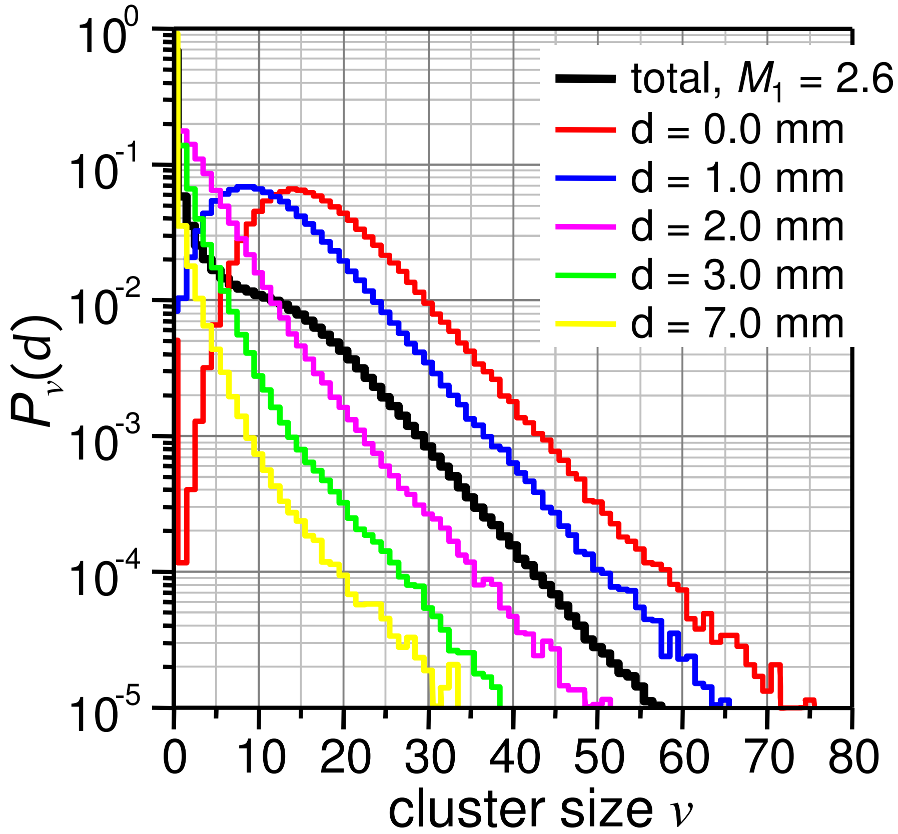
Task 2.1: Multi-scale measurement of particle track characteristics as function of distance between track and target (REG(INFN), PTB)

88 MeV carbon ions in 1.2 mbar C_3H_8

mean cluster size M_1,
narrow beam with offset *d*



cluster size distributions, broad beam and narrow beam with offset *d*



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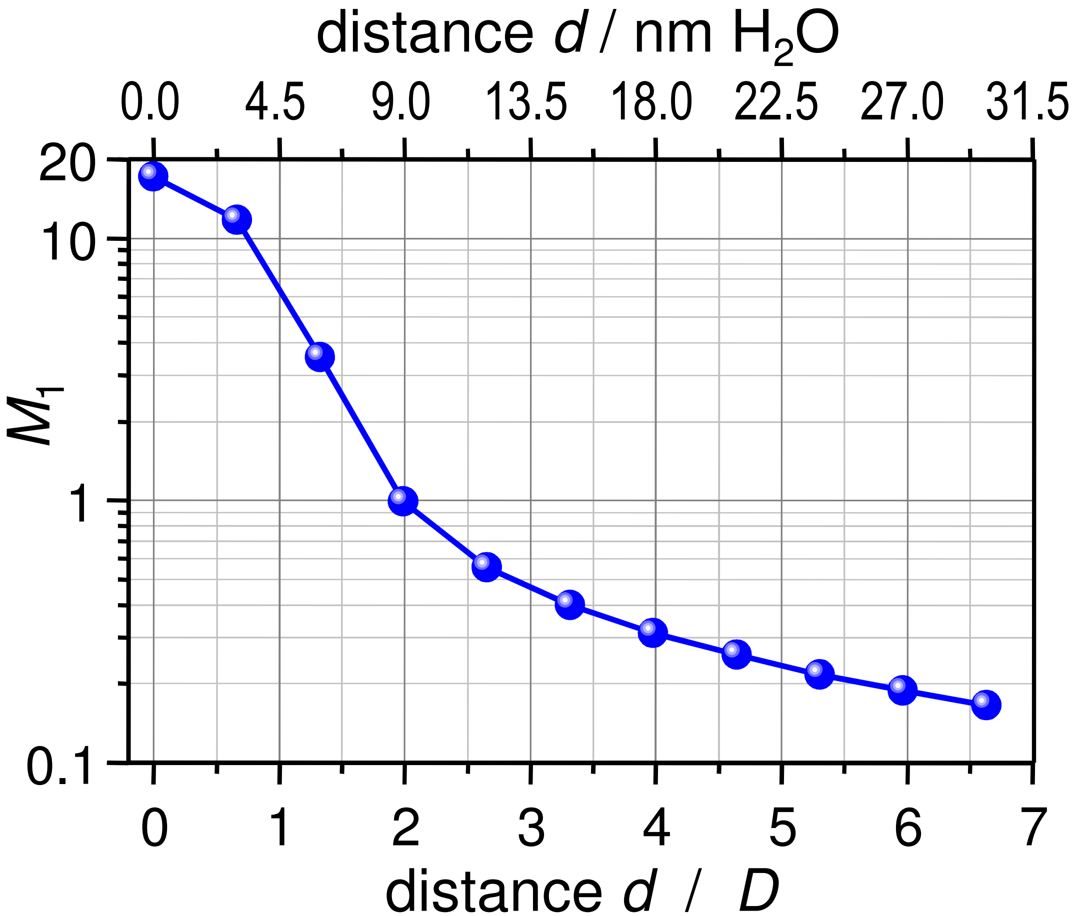


M_1 : mean cluster size
d : primary beam offset
D : sensitive volume diameter

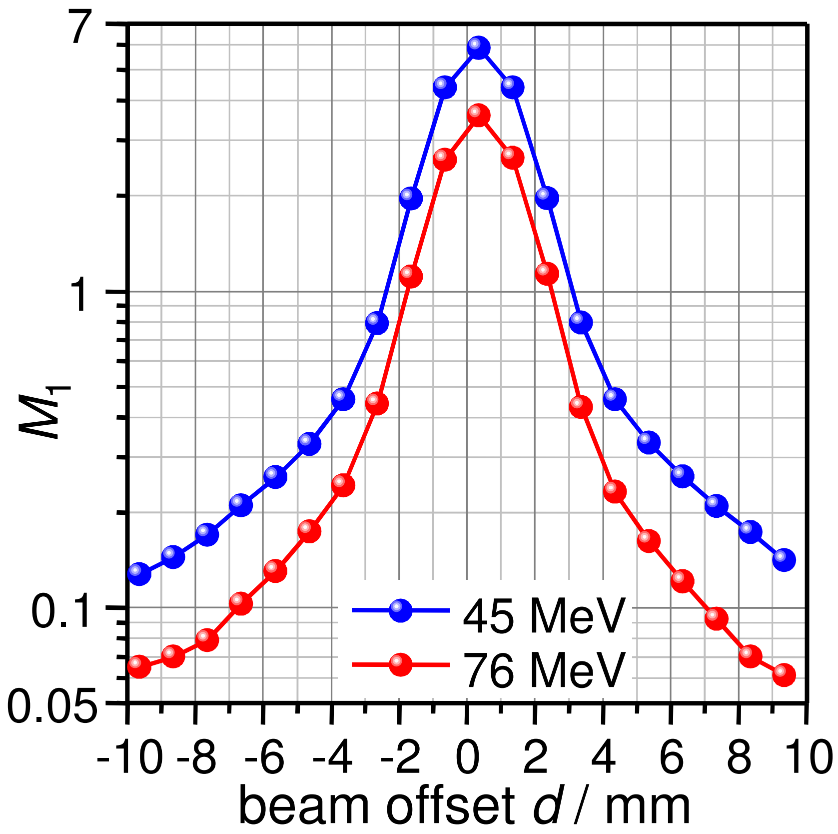
from Monte-Carlo simulations with PTra in liquid H_2O:

1.2 mbar C_3H_8 ↔ 4.5 nm H_2O

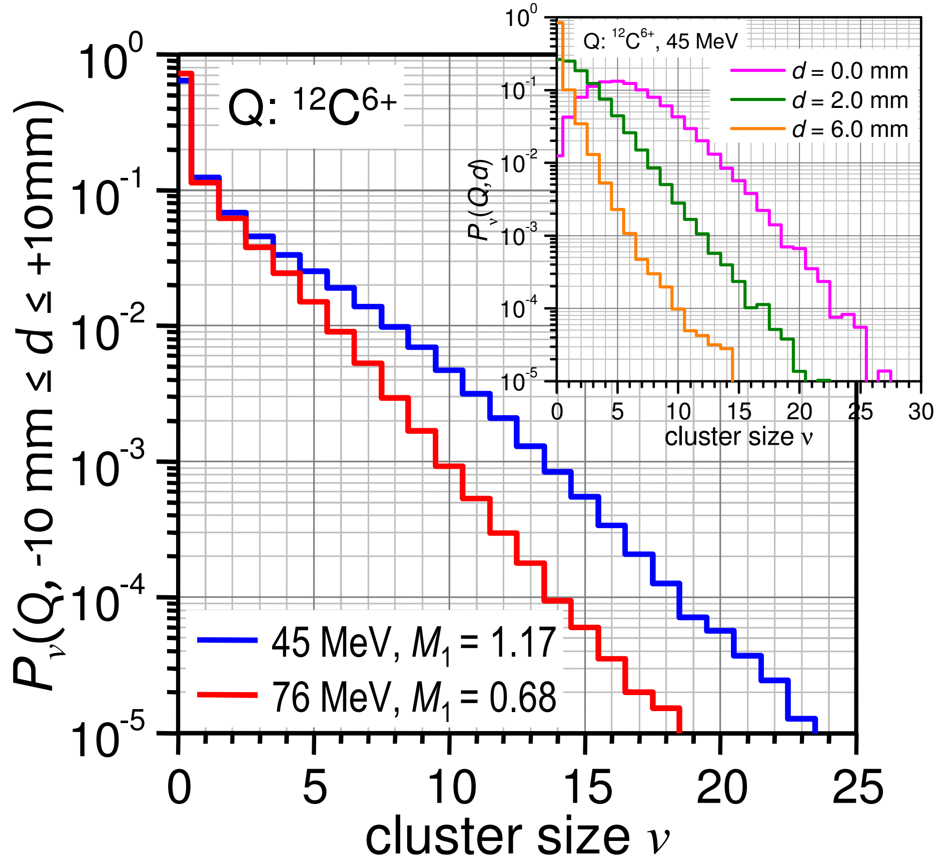
Task 2.2: Multi-scale measurement of particle track characteristics as function of target size (NCBJ, PTB)

45 MeV and 76 MeV carbon ions in 1.2 mbar N_2

mean cluster size M_1,
narrow beam with offset d

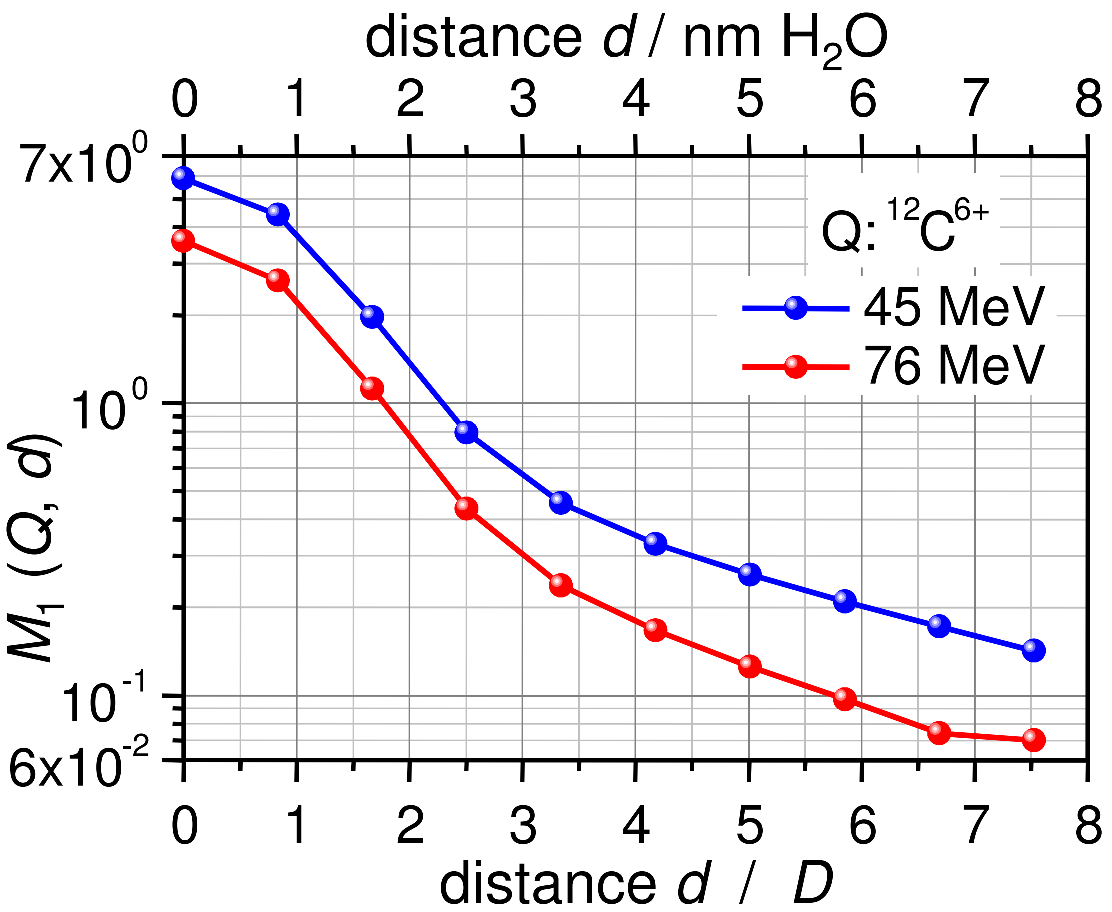


cluster size distributions, broad beam
and narrow beam with offset d



Task 2.2: Multi-scale measurement of particle track characteristics as function of target size (NCBJ, PTB)

45 MeV and 76 MeV carbon ions in 1.2 mbar N_2

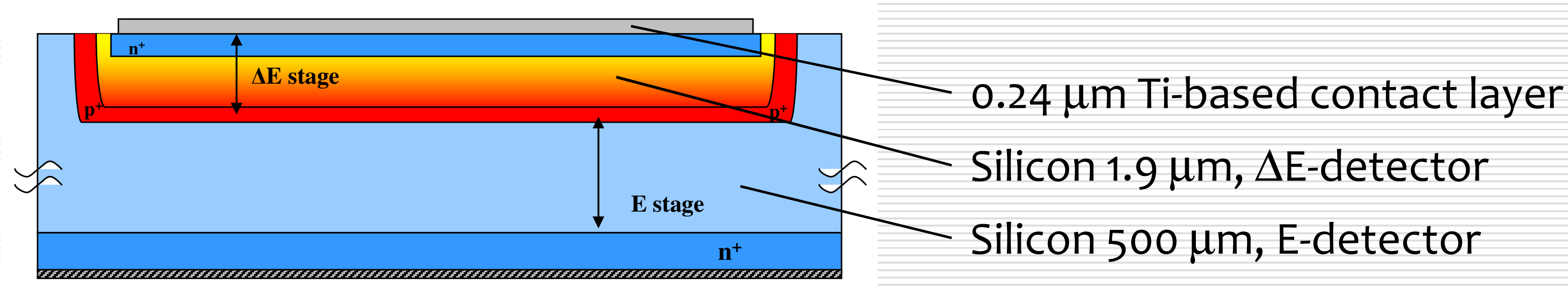


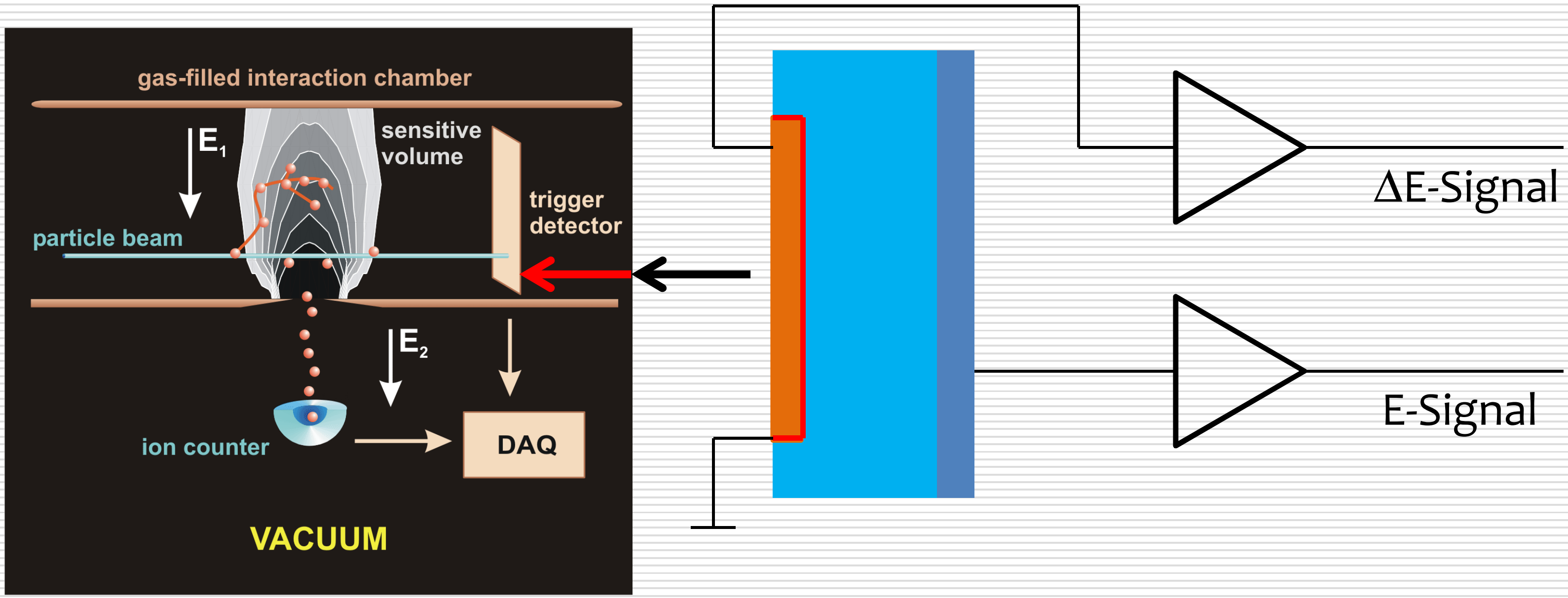
M_1 : mean cluster size
d : primary beam offset
D : sensitive volume diameter

from Monte-Carlo simulations with PTra in liquid H_2O:

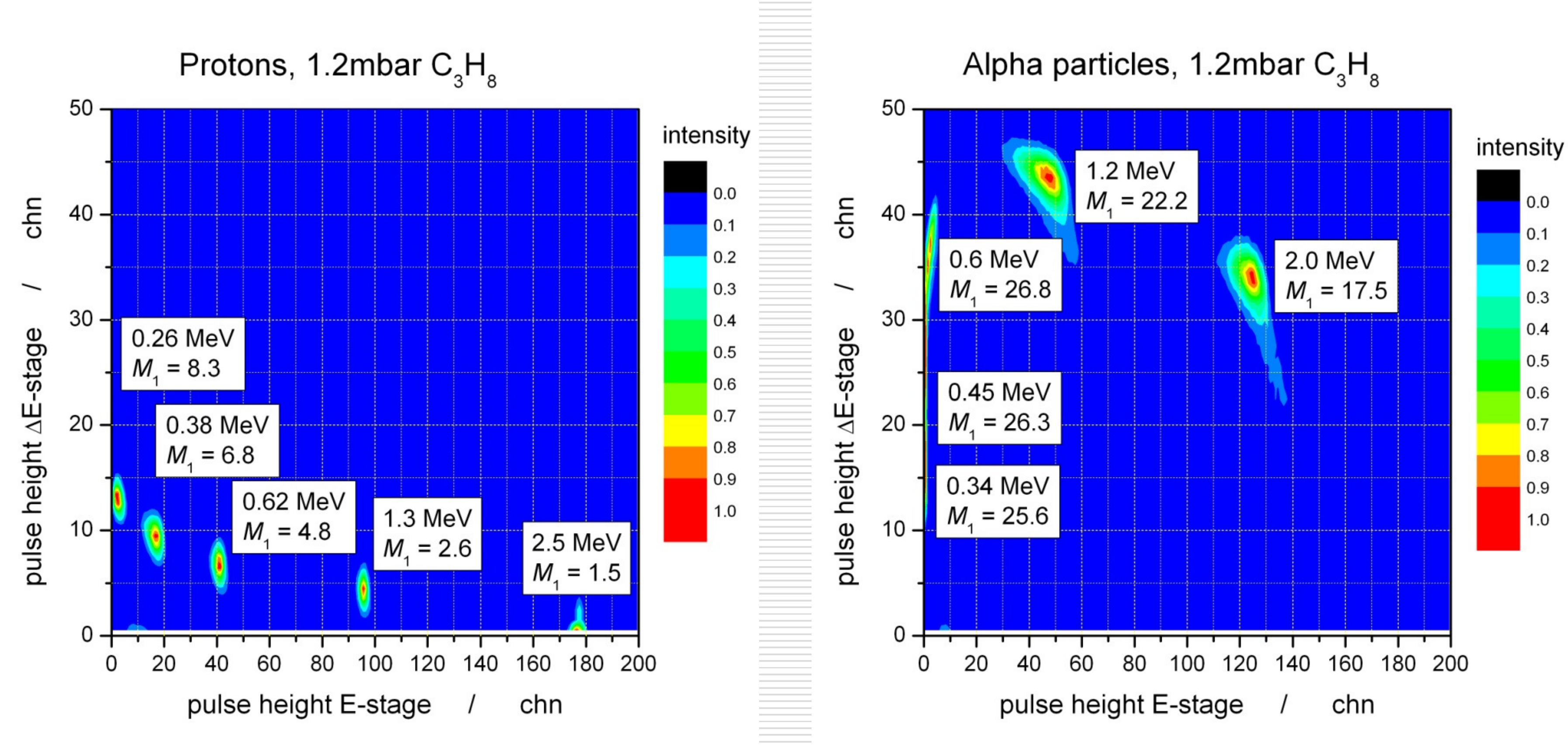
1.2 mbar N_2 ↔ 1.0 nm H_2O

Task 2.3: Multi-scale characterization of particle track structure for selected radiation qualities (PTB, NCBJ, PoliMi, REG(INFN))





Task 2.3: Multi-scale characterization of particle track structure for selected radiation qualities (PTB, NCBJ, PoliMi, REG(INFN))



Task 2.4: Design study for a multi-scale measurement device for track structure properties with nanometer to micrometer resolution
(REG(INFN), NCBJ, PTB)