VHEE experimental activities in CLEAR

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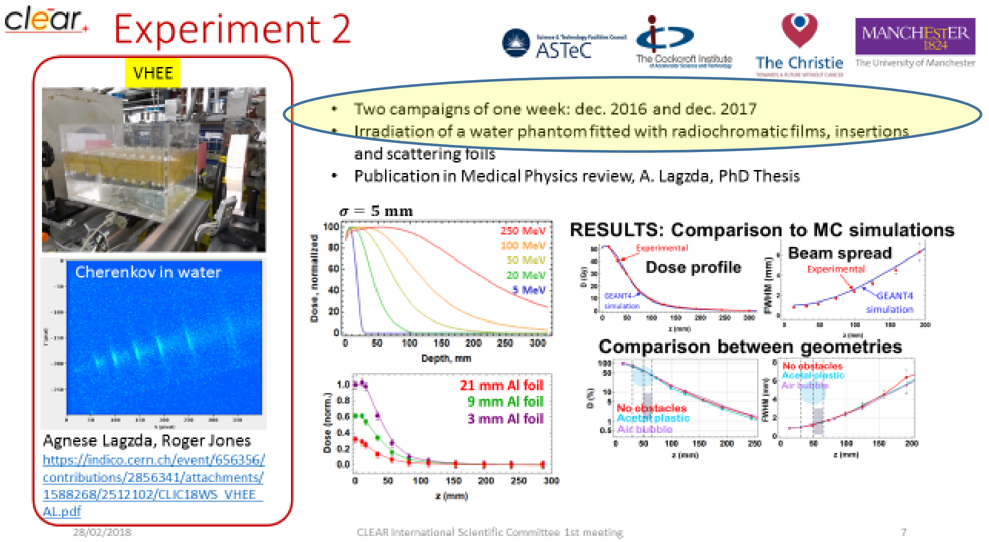
VHEE and CLEAR

- Very High Energy Electron studies for medical applications is now a well established activity in CLEAR
- Started in 2016 with Manchester university (R. Jones, A. Lagzda)



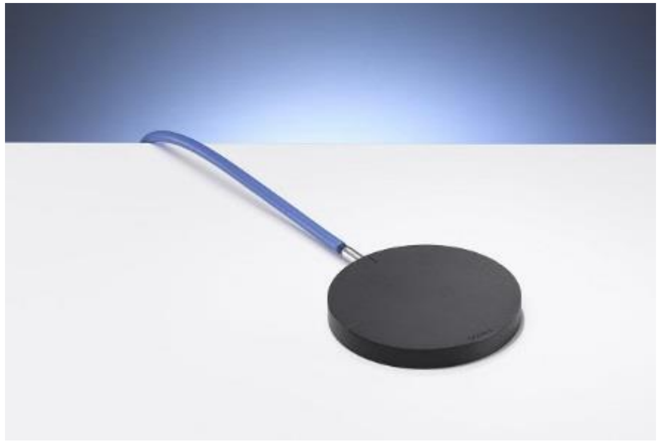
Status of the CLEAR facility, CLEAR International Scientific Committee 1st meeting, 28/02/2018

- In 2018, three additional institutes have joint the VHEE CLEAR users community:
  - National Physical Laboratories (UK)
  - Strathclyde University (UK)
  - Centre Hospitalier Universitaire Vaudois (Switzerland)

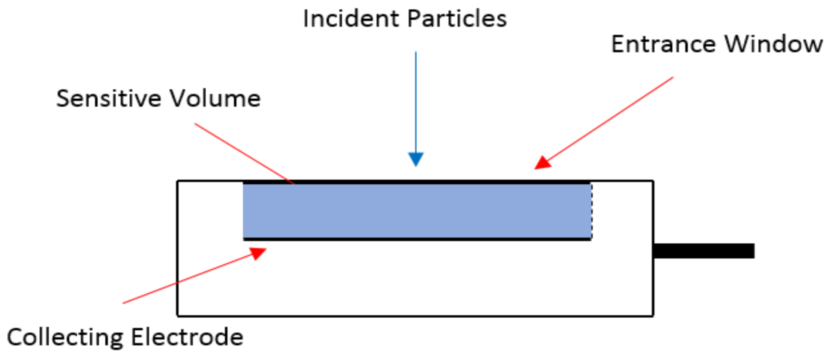
Ion Recombination in ultra-short VHEE beams

Anna Subiel, Michael McManus, NPL

- Ionisation chambers are currently used as a **secondary standard dosimeter in hospitals**, therefore chamber response to high energy ultra-short beams must be well understood.
- Effect on **ion recombination is of high interest**, particularly if this beam type is to be applied to future clinical use.



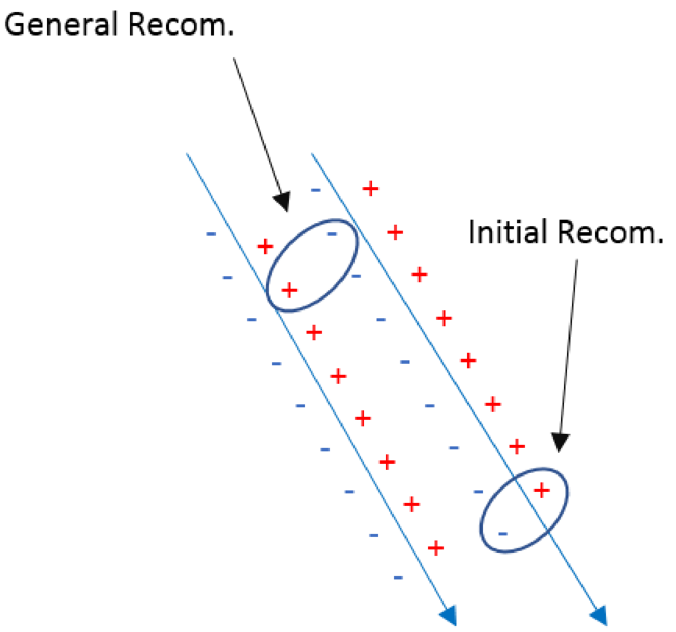
Plane-parallel ionisation chamber



A positive or negative voltage is applied to the collecting electrode to attract ions created from radiation exposure.

Physic of the recombination

Anna Subiel, Michael McManus, NPL

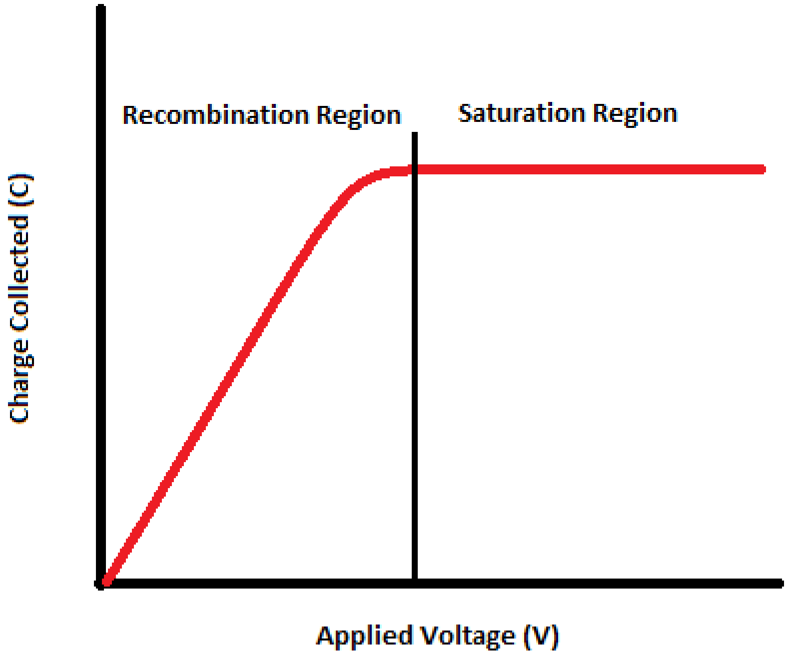


Ion recombination types

- Initial Recombination
  - Recombination along a single charged particle track.
  - **Independent of dose and dose-rate.**
  - More pronounced in highly ionising particles such as alpha-particles.
- General Recombination
  - Recombination between separate charged particle tracks.
  - Directly dependent on charge density i.e the number of ions produced per unit volume.
  - **Dose-rate dependent**.
- General recombination is likely to play a much larger role in recombination effects of ultra-short VHEEs.

Ionisation Chambers – Saturation Curve

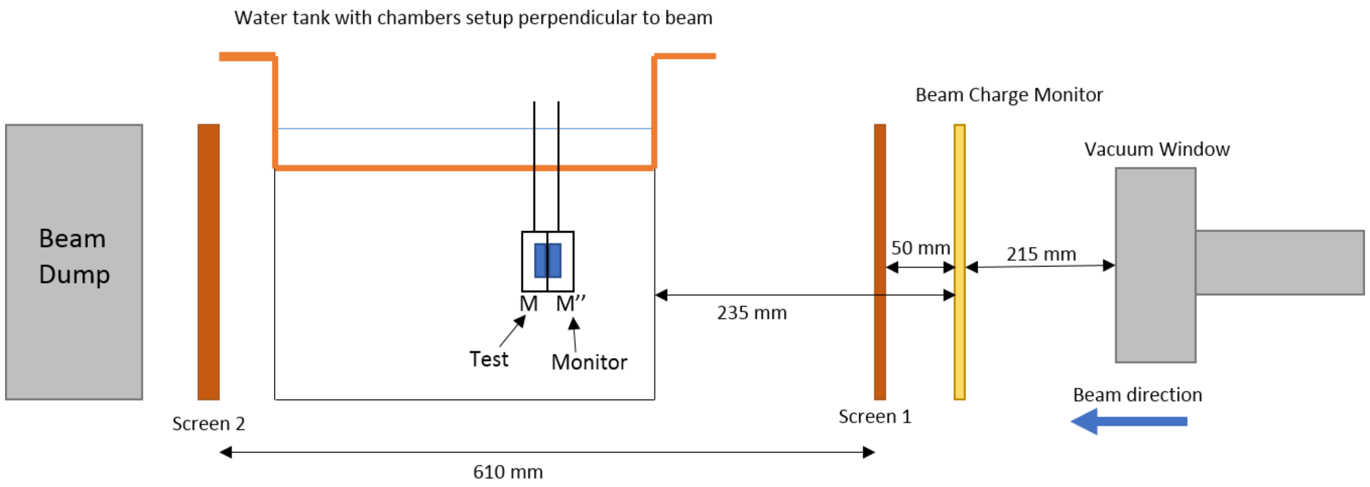
Anna Subiel, Michael McManus, NPL

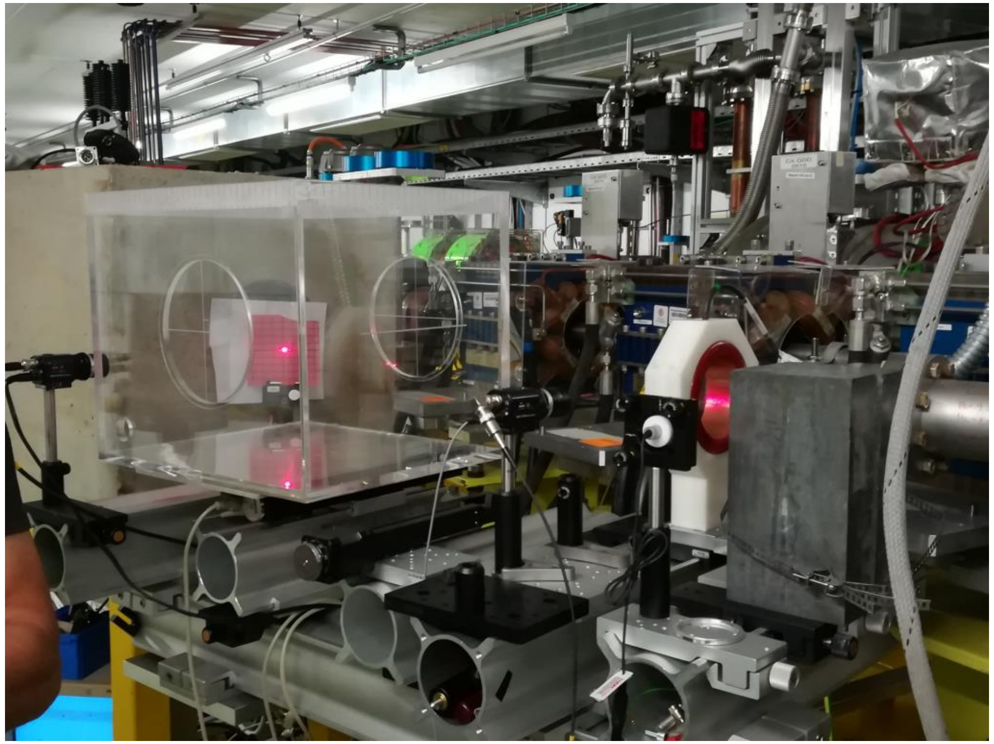


- In theory, if the voltage is increased above the saturation voltage (black line), we should observe 100% charge collection.
- Not realistic due to the onset of electrical breakdown at high voltage and charge multiplication.
- Recombination will therefore always be present despite voltage.

Experimental Setup at CLEAR

Anna Subiel, Michael McManus, NPL





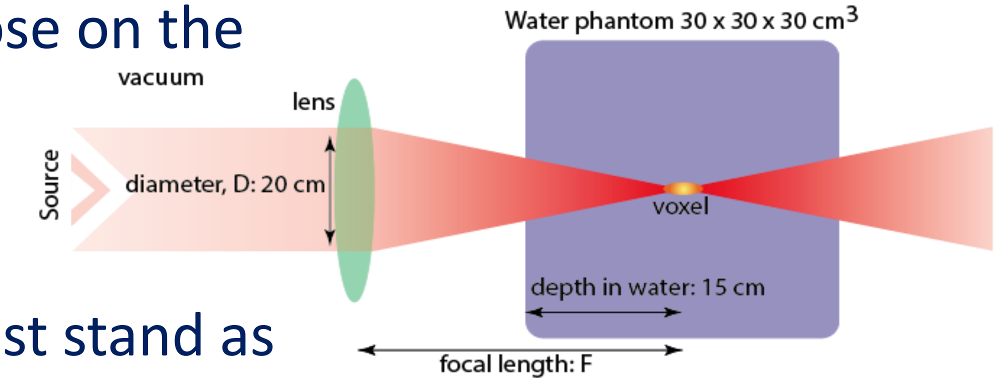
Installed in VESPER and operated from 10 to 15 June 2018
High and low charges tested (3pC to 1 nC)
Bunch length from 1ps to 4ps

VESPER test stand (photo L. Garolfi)

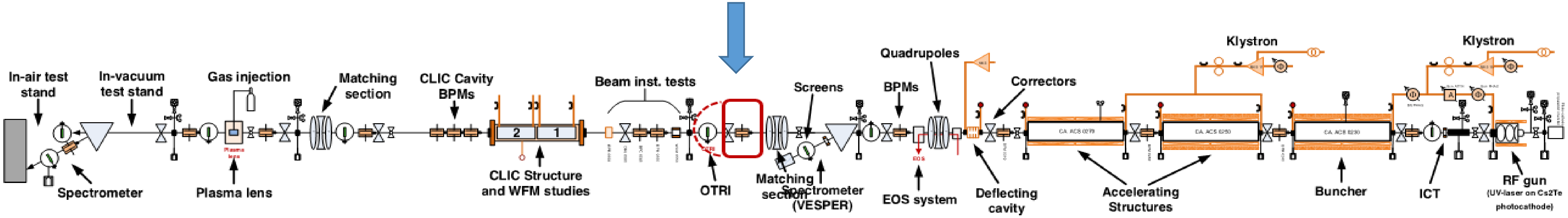
Interesting results but not published yet

Beam focusing in a phantom

- Similar requests from Manchester Univ. and Strathclyde Univ.
- Focus the beam on the tumour to minimize the dose on the nearby healthy tissues

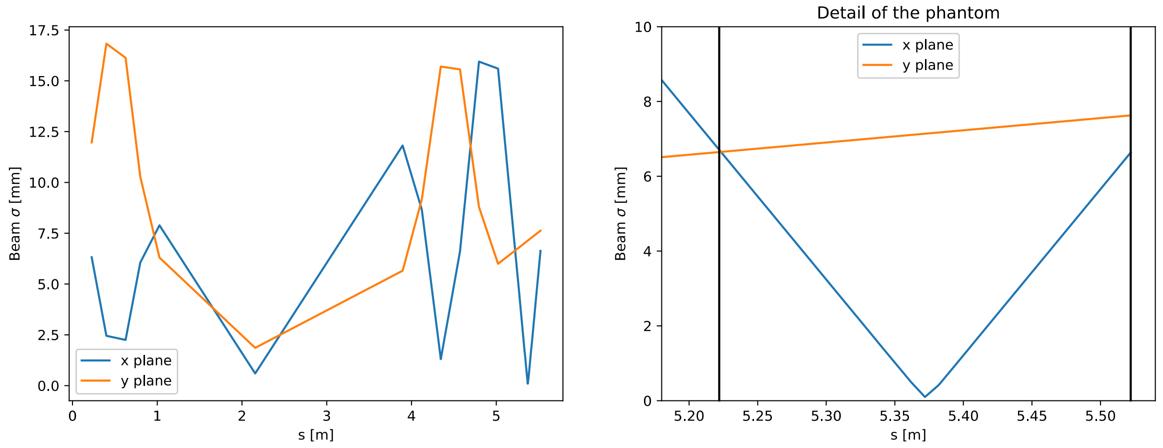


- Difficult to fulfil with the existing CLEAR beam line
- We decided to modify the beam line to create a test stand as close as possible from quadrupoles, with a tight time constraint
  - 1 week for installation – 2 weeks for experiments – 1 week for reconstruction

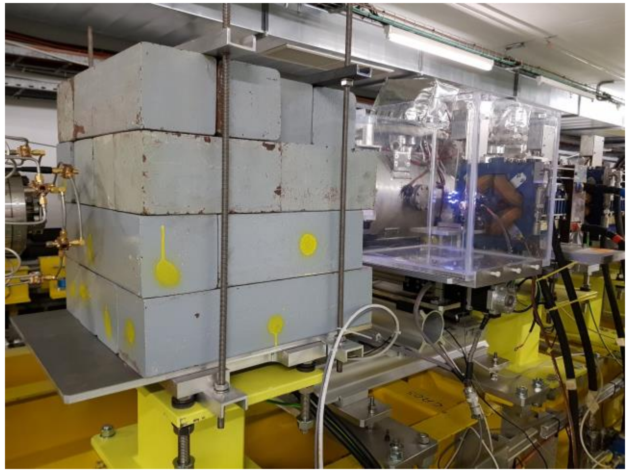


A challenging intervention

- Interruption of the downstream line
- Creation of a provisional dump
- Study of the beam optics
  - Requested quadrupole strength 50% above their specs
- New powers supplies and cables
- New motorized support
- New beam diagnostics
- New exit window
- New beam modelling tool



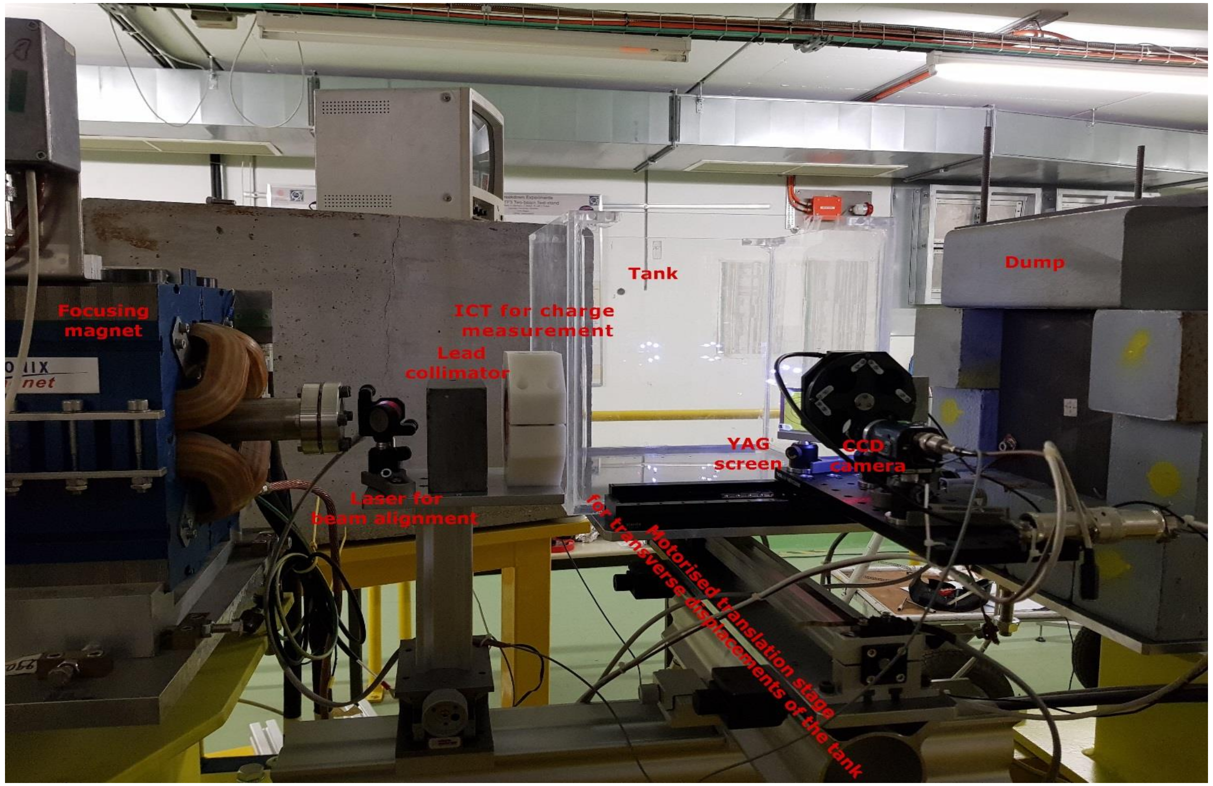
Beam orbit study



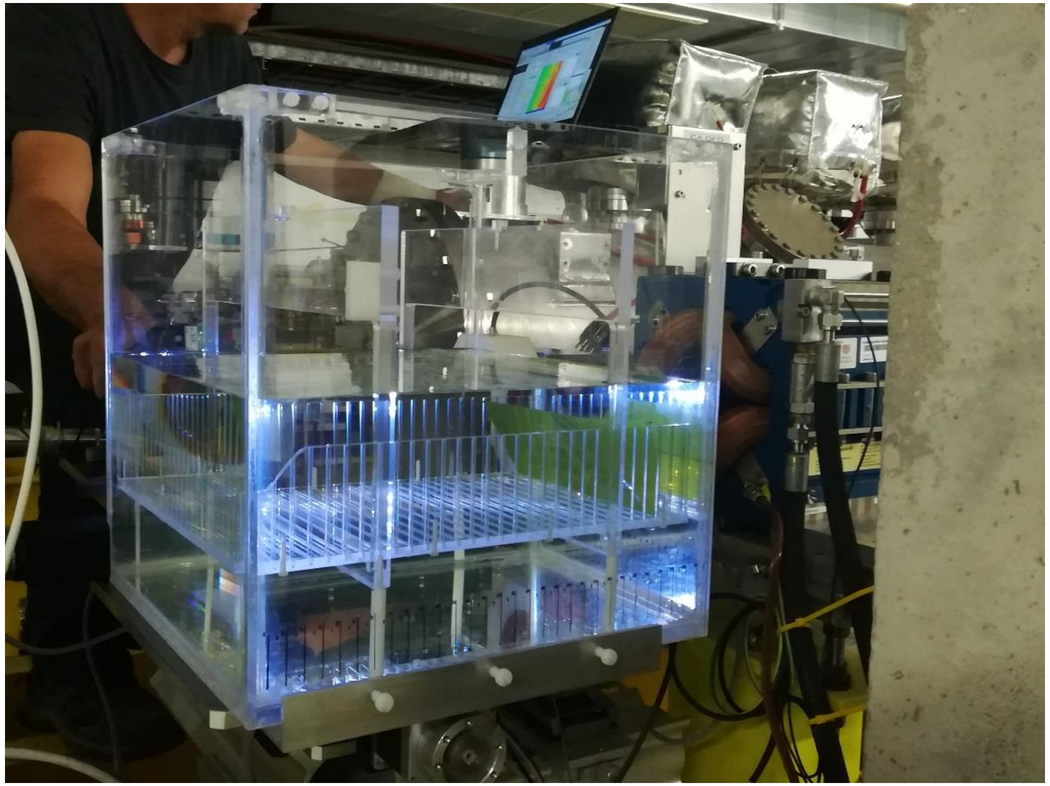
Provisional Beam dump

Motorized support

Installation achieved nearly on time



Experimental set-up



Tank alignment
(photo L. Garolfi)

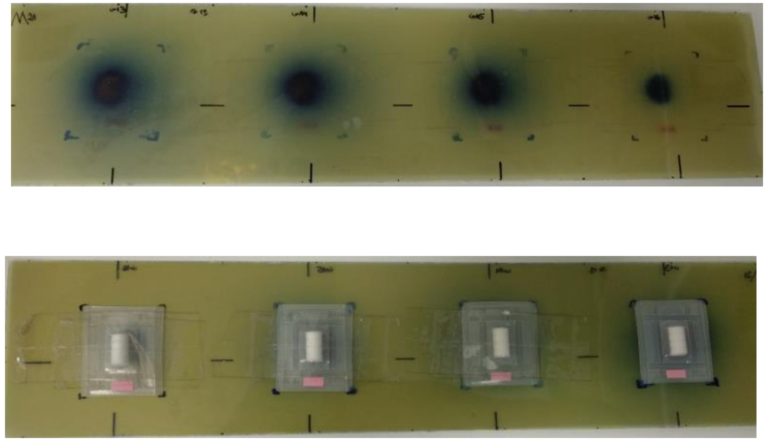
Strathclyde week 17-23 October

- 9 calibration films with alanine pellets
- 6 stacks of 16 films for Profile Depth Dose
- 4 irradiations per film

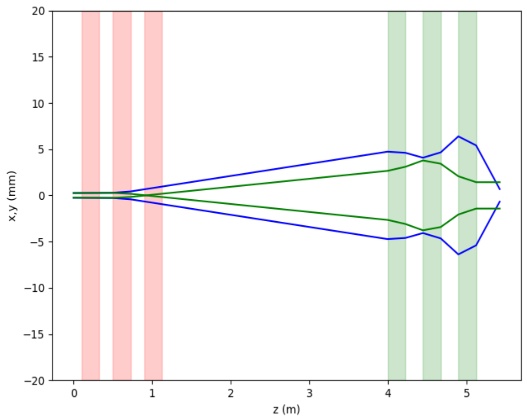
Karolina Kokurewicz,
Enrico Brunetti

Irradiation in air

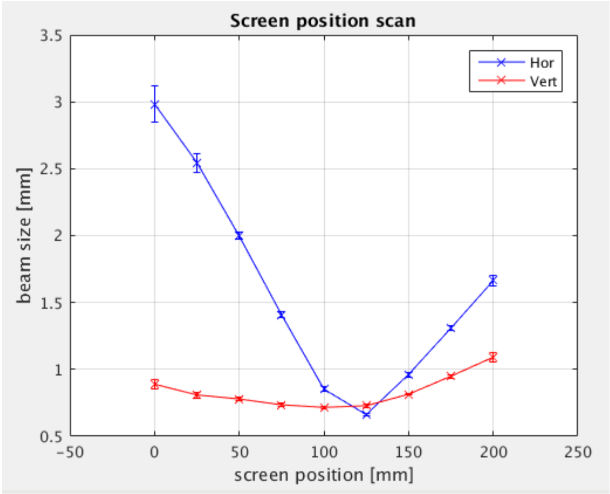
Irradiation in water



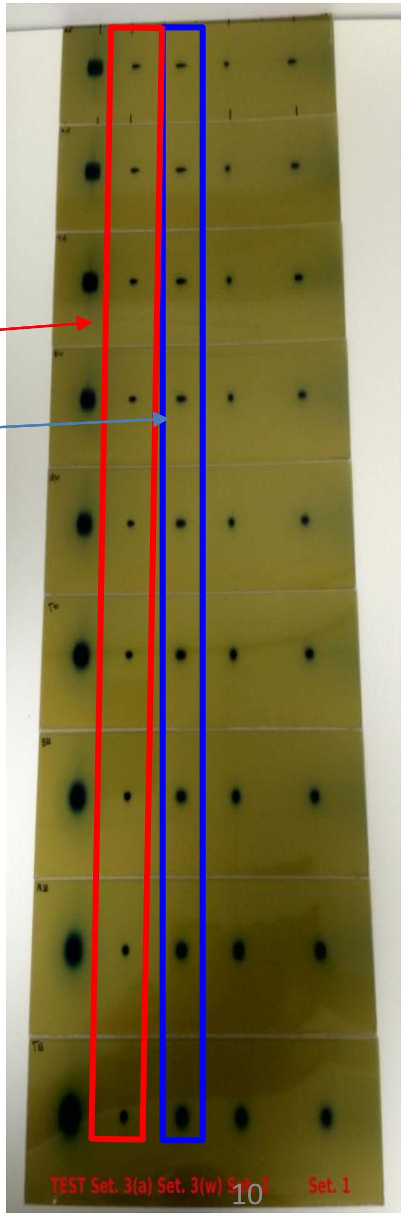
Calibration films, front side and rear side with alanine



Beam model



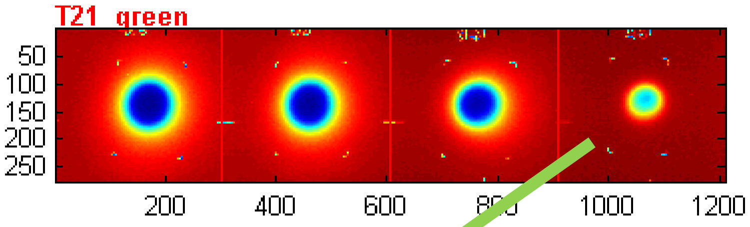
Beam size along propagation in air (movable screen)

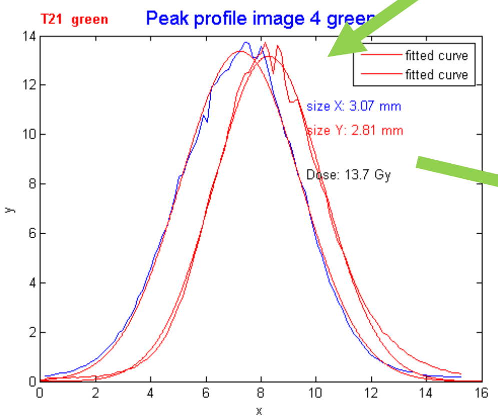


Stack of films for PDD

Dose versus Beam charge density

- Charge density were frequently too large (EBT3 films are optimal up to 30 Gy). Only lowest charge beams are usable.
- No visible energy effect
- Good agreement with the LET found in database (ESTAR)

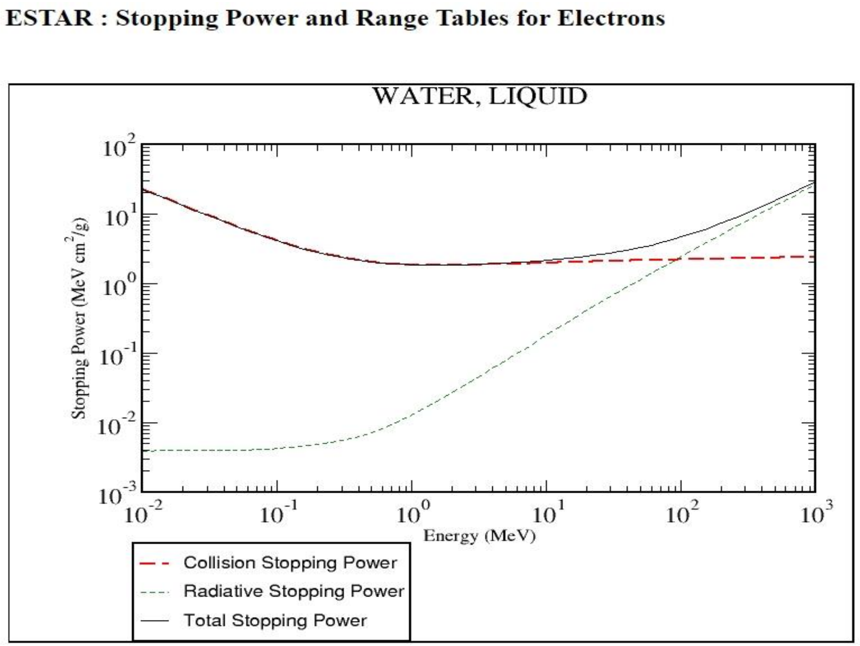




Energy [MeV]	1st charge (~0.6 nC)	2nd charge (~6 nC)
210	228	
151	226	274
56	188	268

Dose / charge density for various energies [Gy/(nC.mm^{-2})]

Film processing to derive a ratio of 237 Gy/(nC.mm^{-2}) corresponding to a LET in water of 2.37 MeV/cm



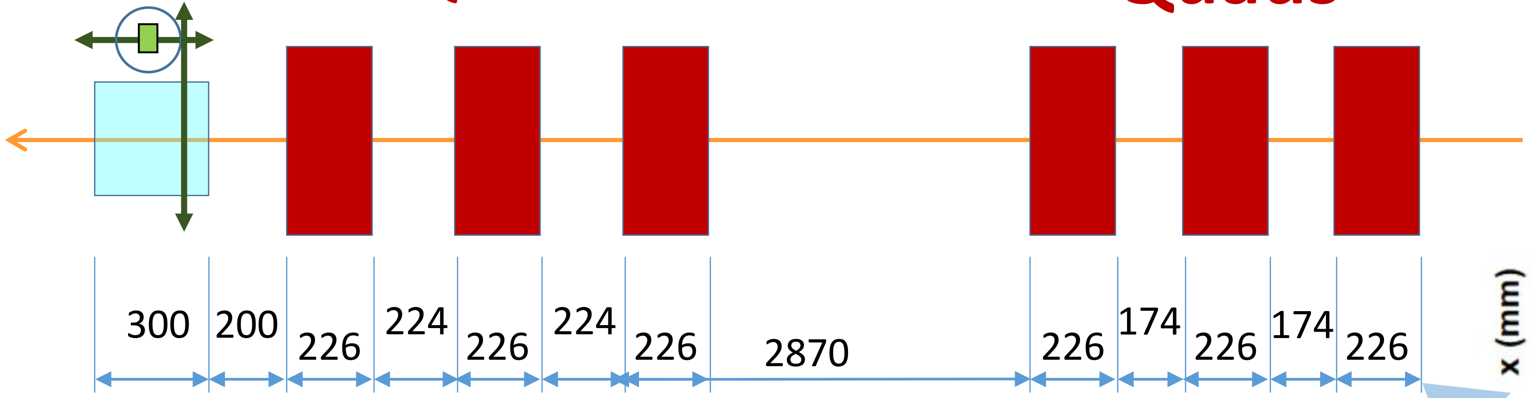
LET for electron in water.
Collision Stopping Power 2.26 MeV/cm

clear

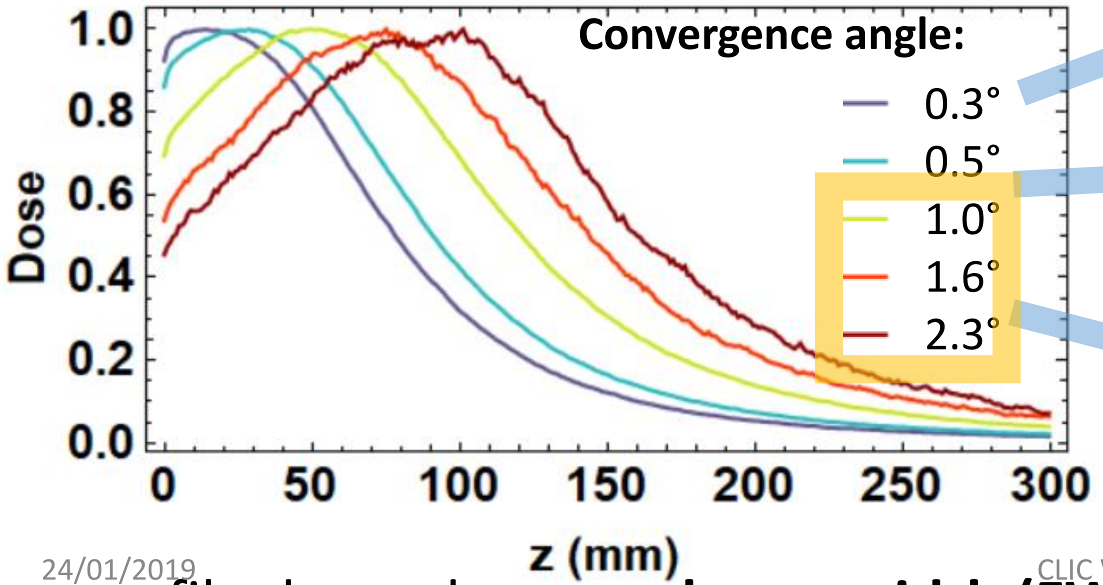
VHEE EXPERIMENTS IN 2018

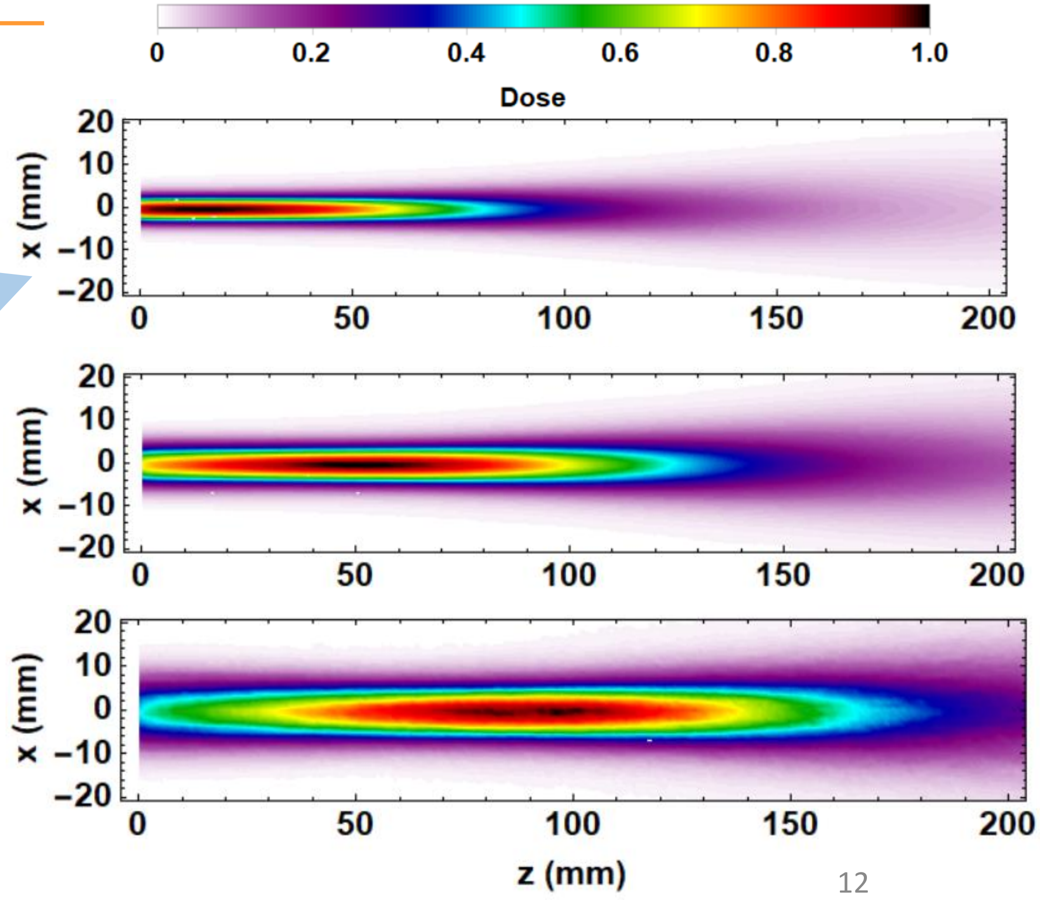
Preliminary simulations before experiments

Agnese Lagzda, Roger Jones



- Experiments with > **2° converging beams** planned at CERN's CLEAR user facility in 2018.





Dose profile dependence on **beam width (FWHM)**.

VHEE EXPERIMENTS IN 2018

BEAM PARAMETERS:

Energy	34 - 205 MeV
Energy spread	< 0.5 MeV FWHM
Bunch charge	~15 pC
Beam spot size, σ	1.2 –8 mm
Charge Jitter	~20 %

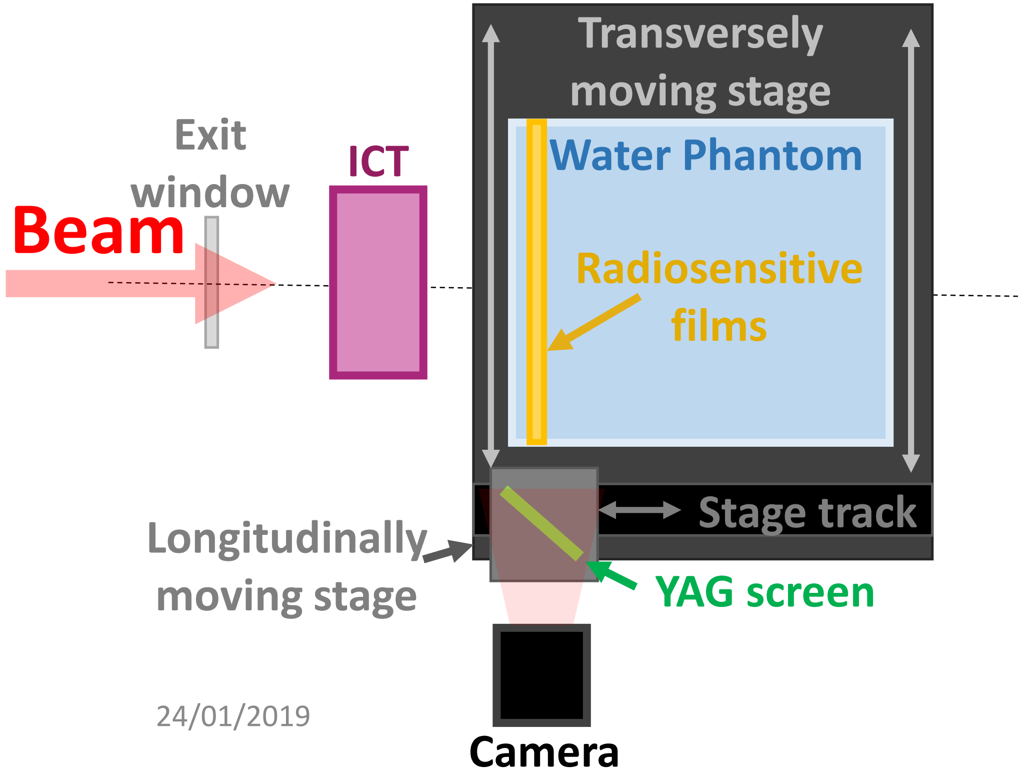
PLAN:

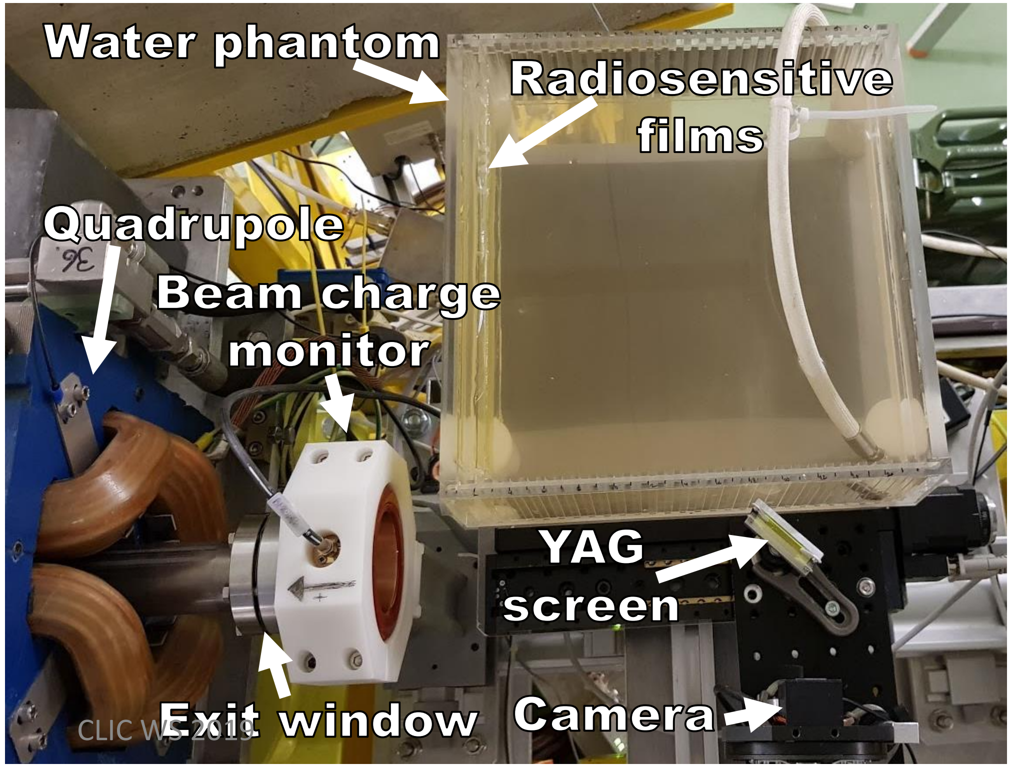
Agnese Lagzda, Roger Jones

5 days

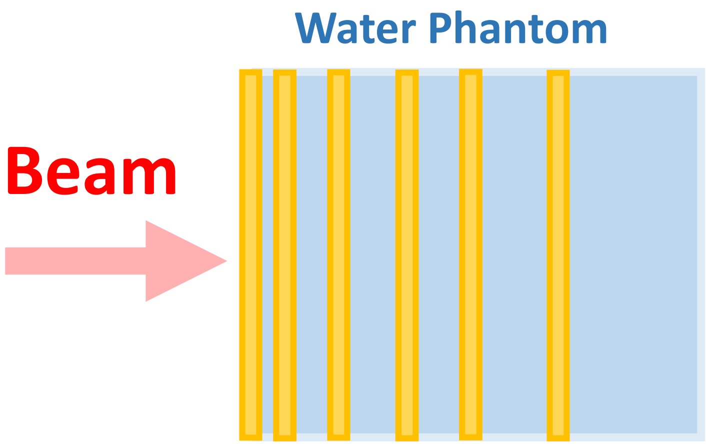
1) Radiosensitive film reaction differences at electron energies 50– 205 MeV
2) Converging beam profiles in water at energies 50 – 205 MeV
3) Cherenkov light measurements during irradiations

IRRADIATION SET-UP:



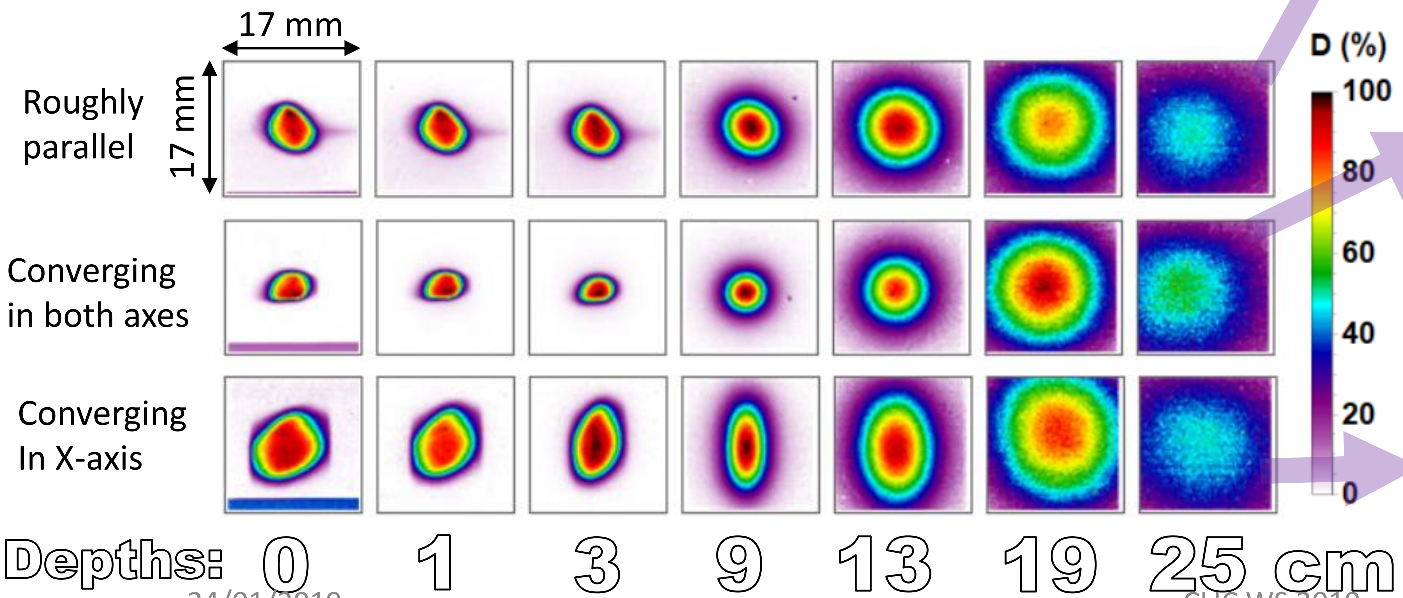


VHEE EXPERIMENTS IN 2018 205 MeV

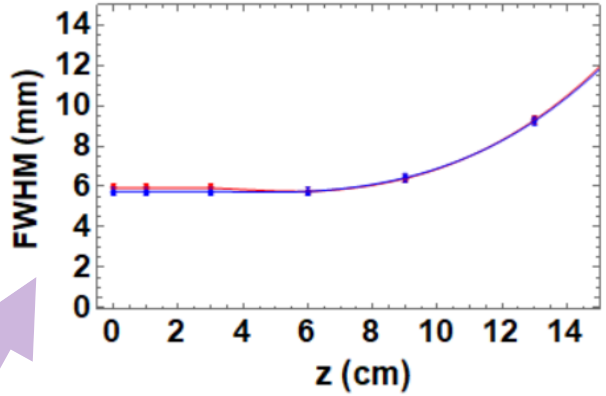


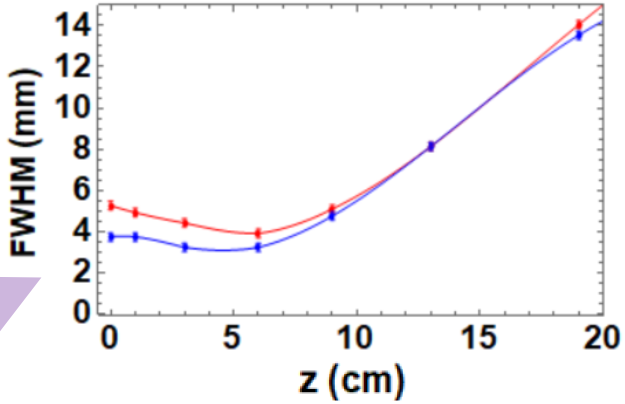
Radiosensitive films inserted at:
0, 1, 3, 6, 9, 13, 19, 25 cm.

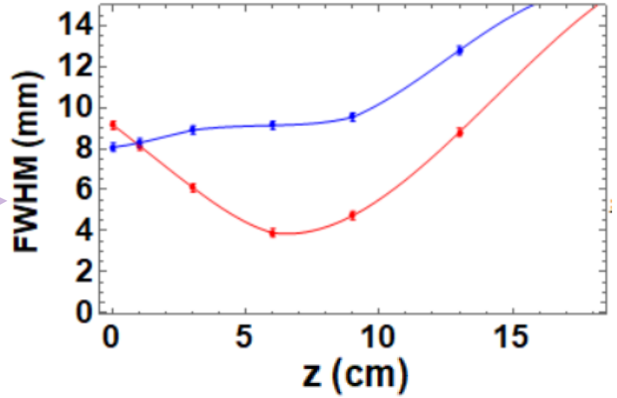
200 MeV parallel and converging beams:

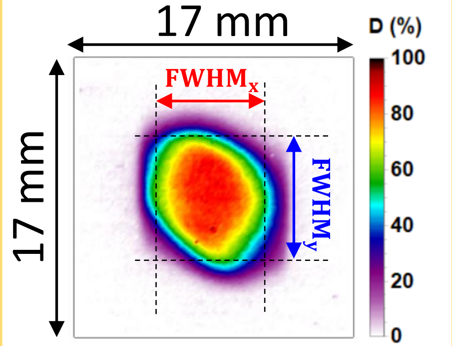


x and y envelope in water









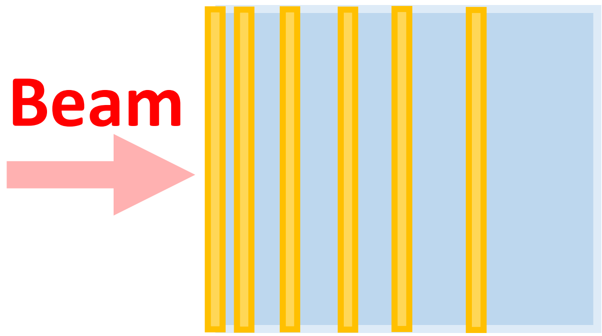
Evolution of maximum FWHM were measured in both planes

$FWHM_x$
$FWHM_y$

It was possible to decrease $FWHM_x$ **from 9.1 to 3.8 mm**

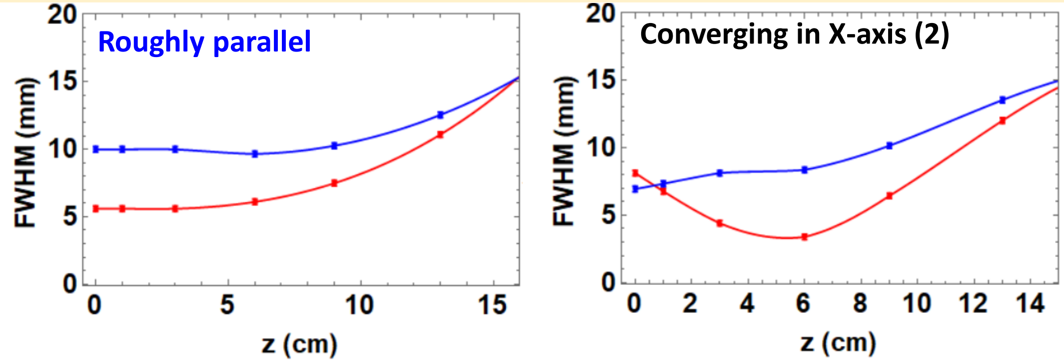
X and Y axis FWHM envelopes in water with a 2nd degree interpolation curve

VHEE EXPERIMENTS IN 2018 160 MeV

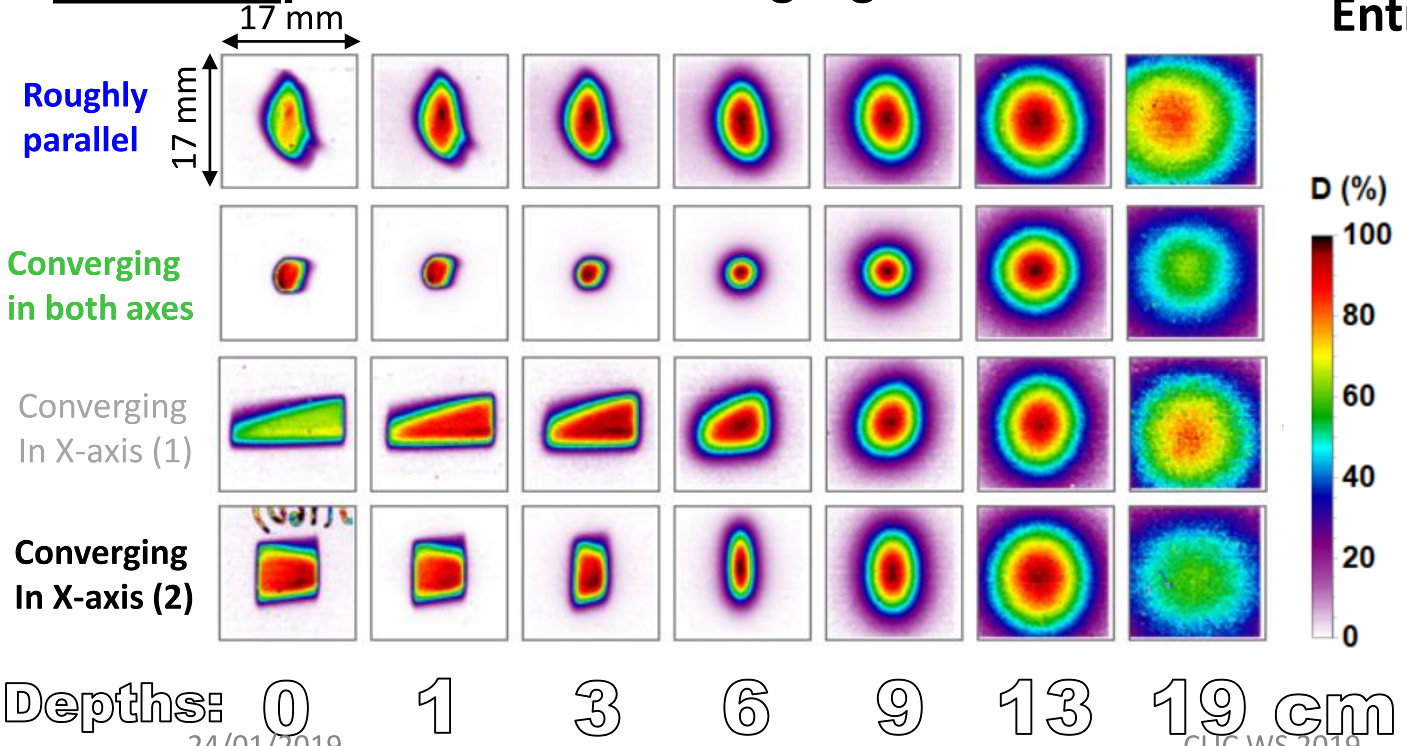


Radiosensitive films inserted at:
0, 1, 3, 6, 9, 13, 19, 25 cm.

Beam envelope in water:



160 MeV parallel and converging beams:



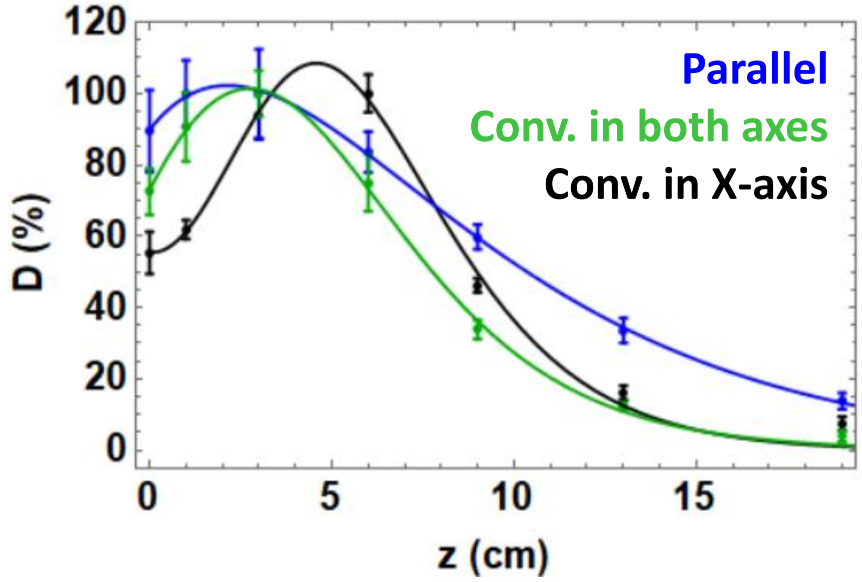
Entrance doses: $\frac{D_0}{D_{max}} \times 100\%$

89.5%

72.5%

73.6%

55.4%



On-axis PDD with best analytical fit.

3rd Manchester campaign summary

Agnese Lagzda, Roger Jones

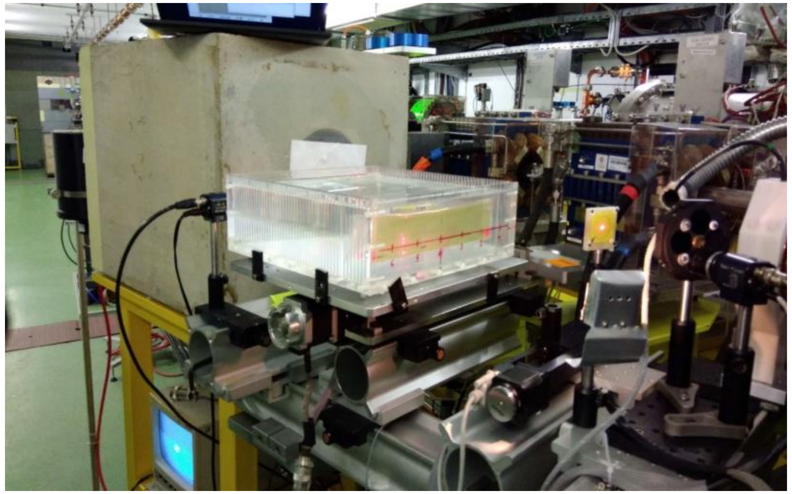
- EBT-XD radiosensitive films have a consistent dose reaction to various energy beams.
- Possibility of reducing beam waist in water geometries was proven
  - FWHM was reduced more than 2 times from 9.8 to 3.8
  - Entrance dose was reduced from 89% to 55%
  - Reduction in exit dose was noted

Flash Effect with VHEE

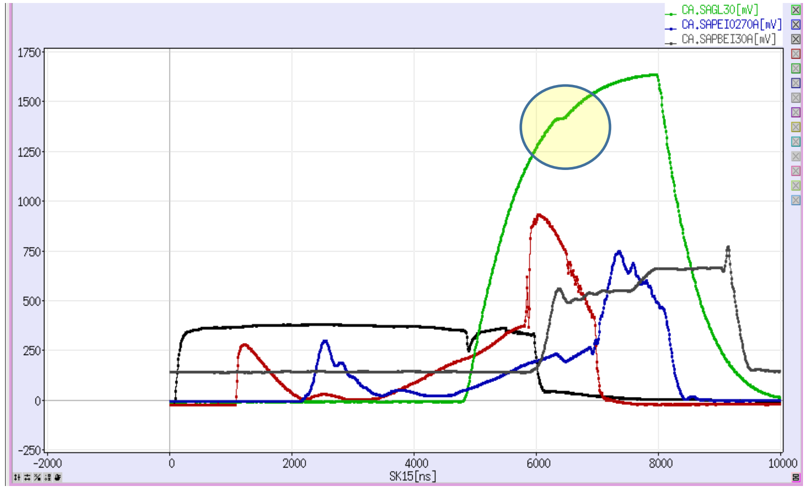
Marie-Catherine Vozerin, Patrick Goncalves, C. Bailat

See also "Perspectives for electron FLASH therapy, P.-G. Montay-Gruel, this cession 12:00

- Generate the total dose (~10 Gy) on biological dosimeters in a single pulse (<100 ms)
- Request accurate accelerator settings to limit the energy spread
- Two days of experiment 12-13 December



Set-up in VESPER

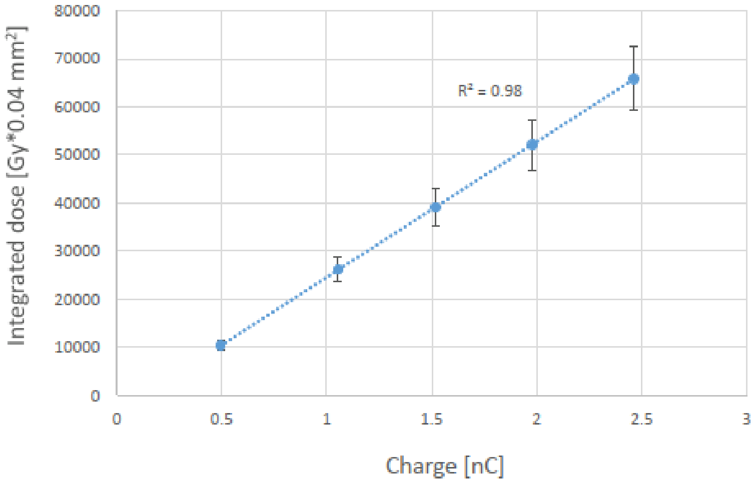


Beam loading compensation

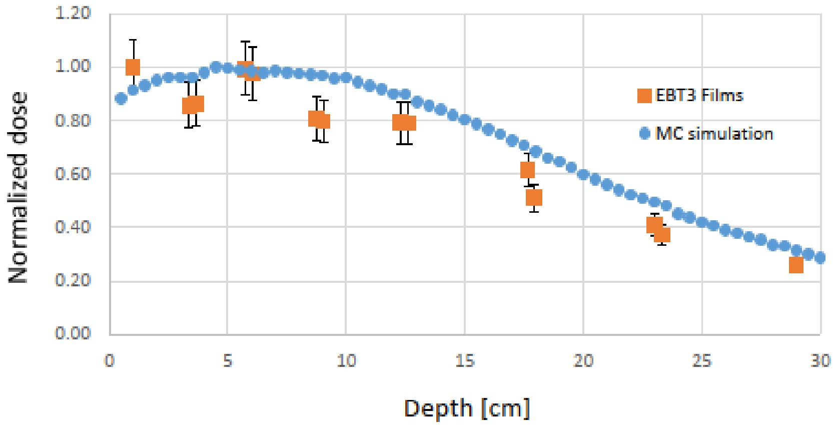
First experiment objectives

Marie-Catherine Vozerin, Patrick Goncalves, C. Bailat

- Calibration
- Profile Depth Dose
- Biological dosimeters irradiation feasibility

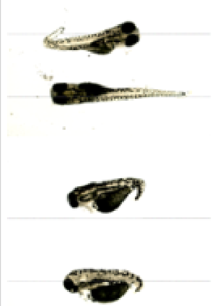


Integrated dose vs. beam charge



Profile Depth Dose

Irradiated

Tube	D_{mean} [Gy]	SD [%]	Survival 5 dpf	Morphology 5 dpf
1-8	7.4	8.4	5%	
2-8	6.2	20.9	10%	

Biological results

Conclusions

- The VHEE community finds in CLEAR a valuable and responsive facility.
- Users are already requesting beam time for 2019 (NPL: absolute dosimetry with calorimeter, Manchester Univ. plasmid irradiation, CHUV: Flash effect on biological dosimeters, Strathclyde Univ. : Imaging of the deposited dose…)
- A dedicated beam line is under study (ex: larger quadrupole aperture, non dispersive line)

Thank you for your attention