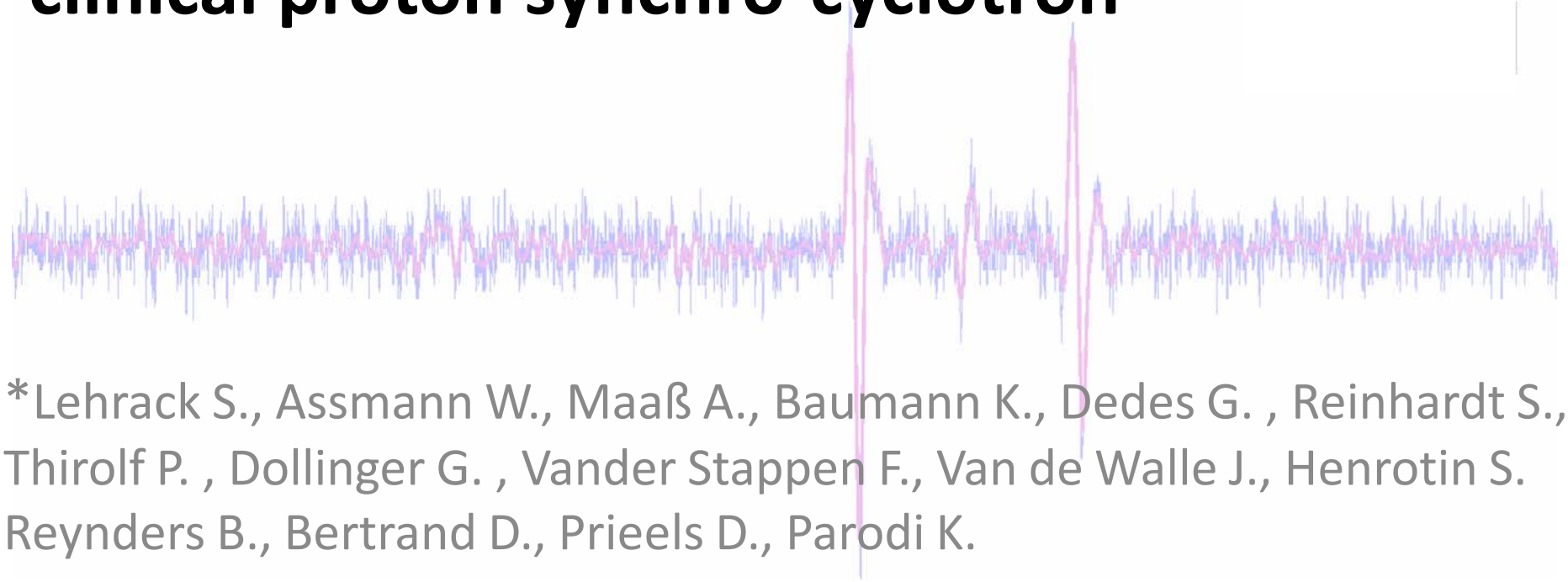
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Munich-Centre for Advanced Photonics (MAP)

Range Verification with Ionoacoustics: simulations and measurements at a clinical proton synchro-cyclotron



*Lehrack S., Assmann W., Maaß A., Baumann K., Dedes G. , Reinhardt S., Thirolf P. , Dollinger G. , Vander Stappen F., Van de Walle J., Henrotin S. Reynders B., Bertrand D., Prieels D., Parodi K.

Ionoacoustics

Stopping of ions causes **local heating** and **pressure wave**:

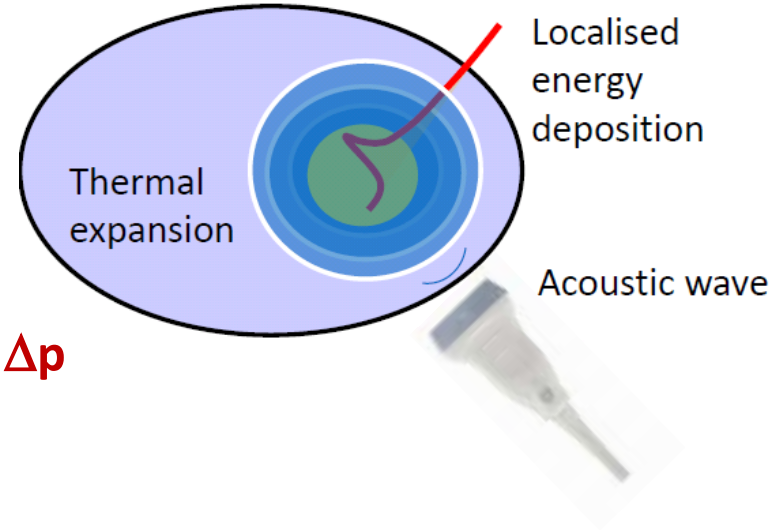
$$\frac{dV}{V} = -\kappa dp + \beta dT$$

$$p = \frac{\beta}{\kappa \rho C_V} D \quad *$$

κ isothermal compression
β volume expansion coefficient
D deposited ion dose
* in thermal and stress confinement

Ionoacoustic effect

Ultrasound signal from Bragg peak (BP) for *in-vivo* position determination?

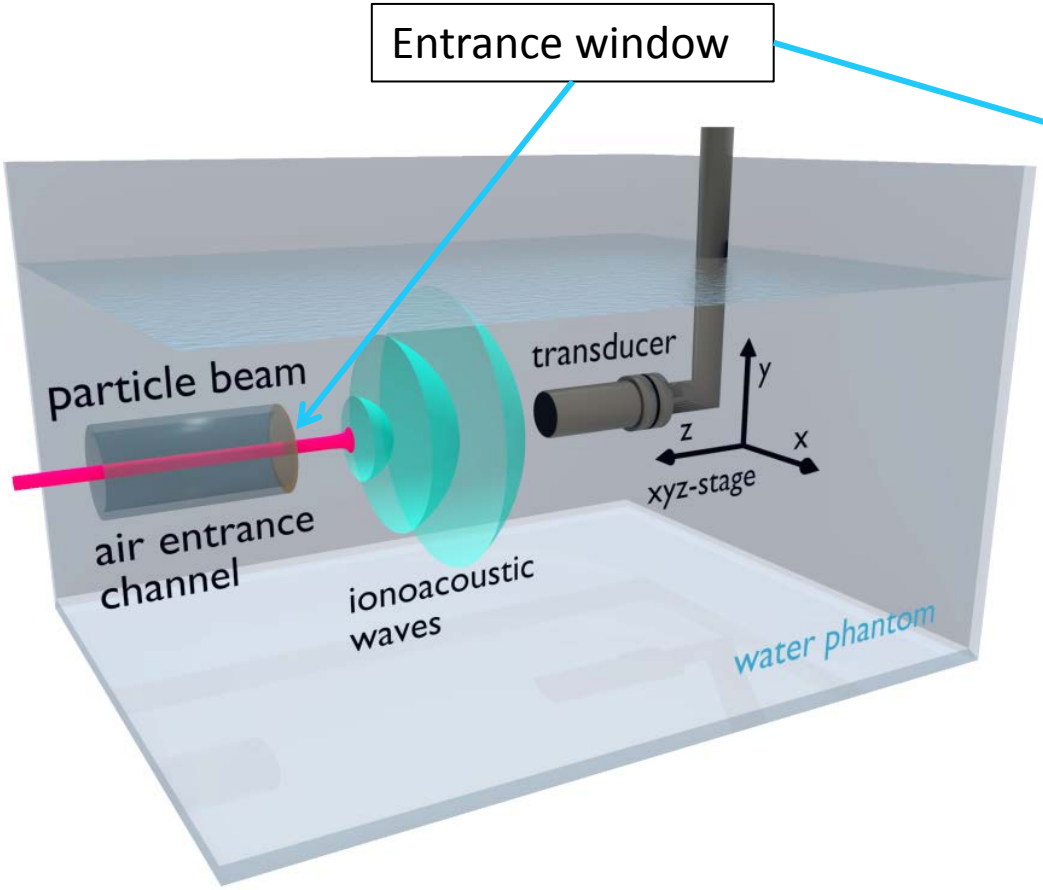


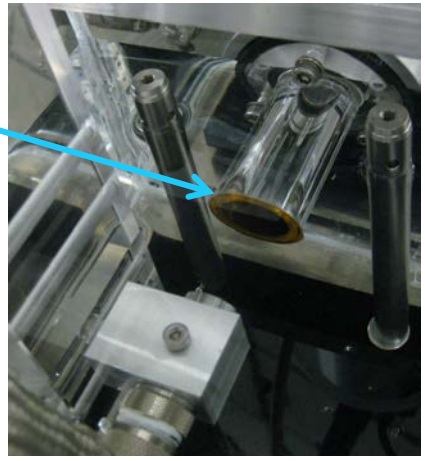
Rule of Thumb:

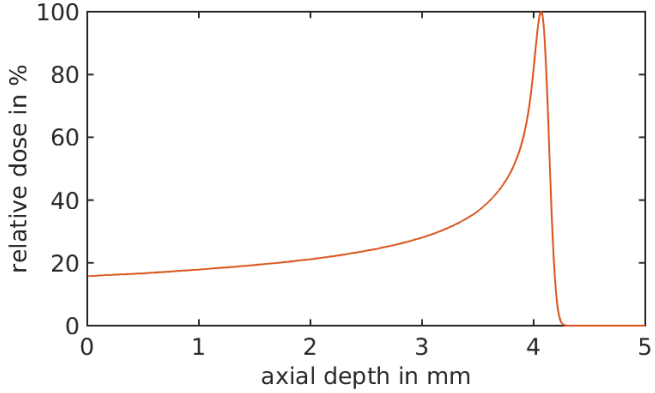
1 Gy dose → 0.25 mK ΔT → 1 mbar Δp

weak effect! But direct and fast method

Proof of Principal with 20 MeV

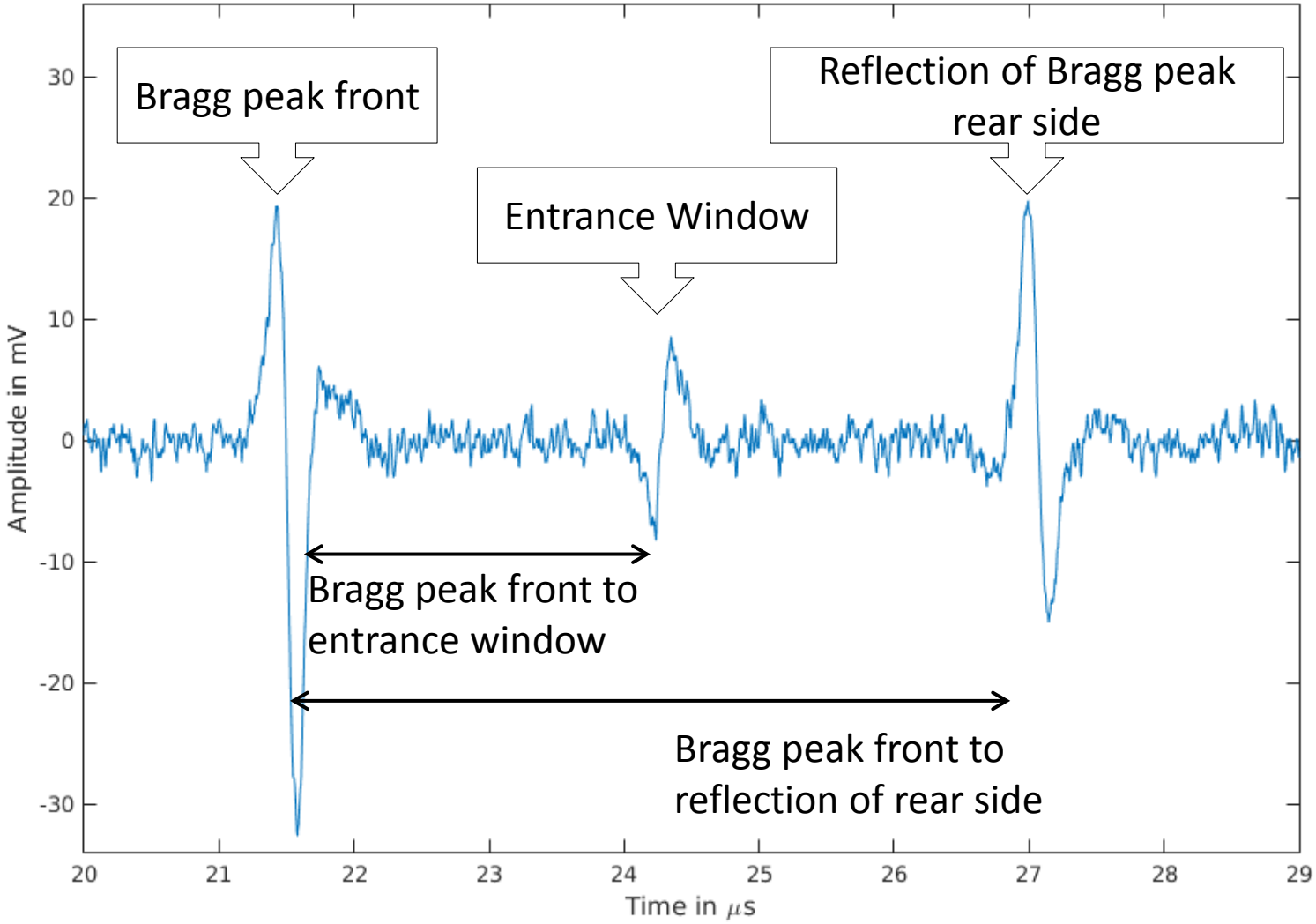






W. Assmann *et al.*, Med.Phys. 42, 2 (2015), 567

Ionoacoustics signal



Results

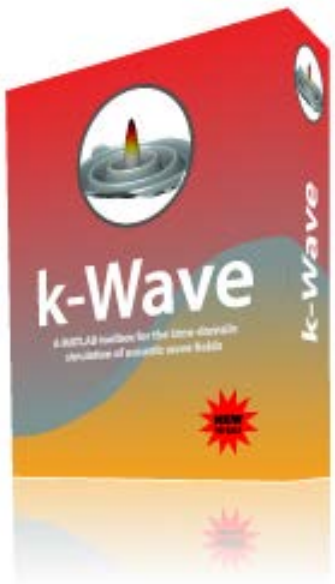
Range determination by signal integration

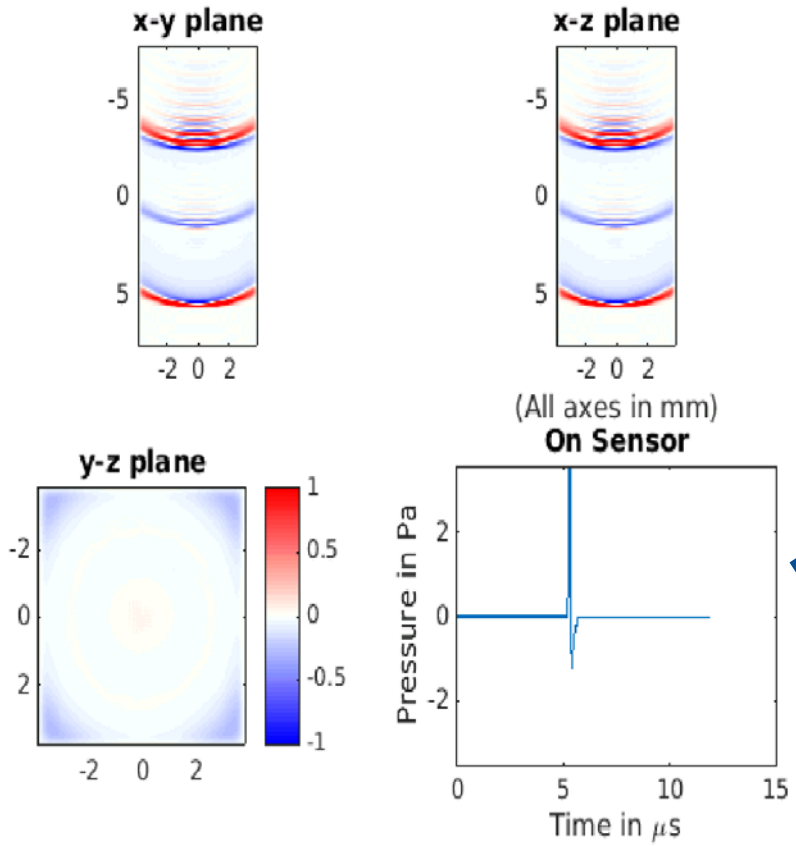
Vacuum window	Kapton	Titanium	Titanium
Proton energy [MeV]	**20**	**20**	**21**
Geant4 simulation [μm]	4040 +- 30	4070 +- 30	4450 +- 30
Experiment [μm] Bragg peak – foil Bragg peak – reflection	 3990 +- 40 4020 +- 20	 4090 +- 40 4060 +- 20	 4490 +- 40 4460 +- 20
Difference between simulation and exp [μm]	**-50** **-20**	**+20** **-10**	**+40** **+10**

Uncertainty of Geant4 simulation: beam path geometry
mean excitation energy

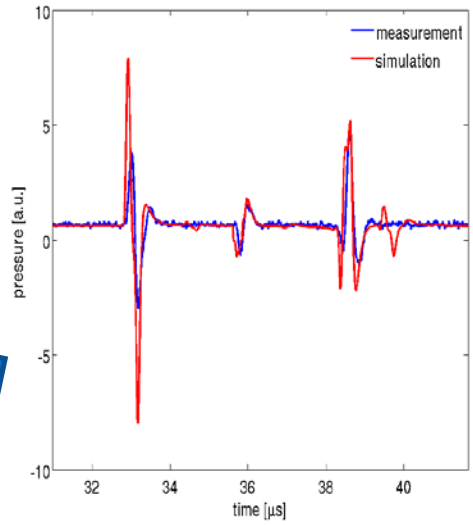
Master Thesis A. Maaß, 2015, in preparation

Acoustic Simulation
k-Wave





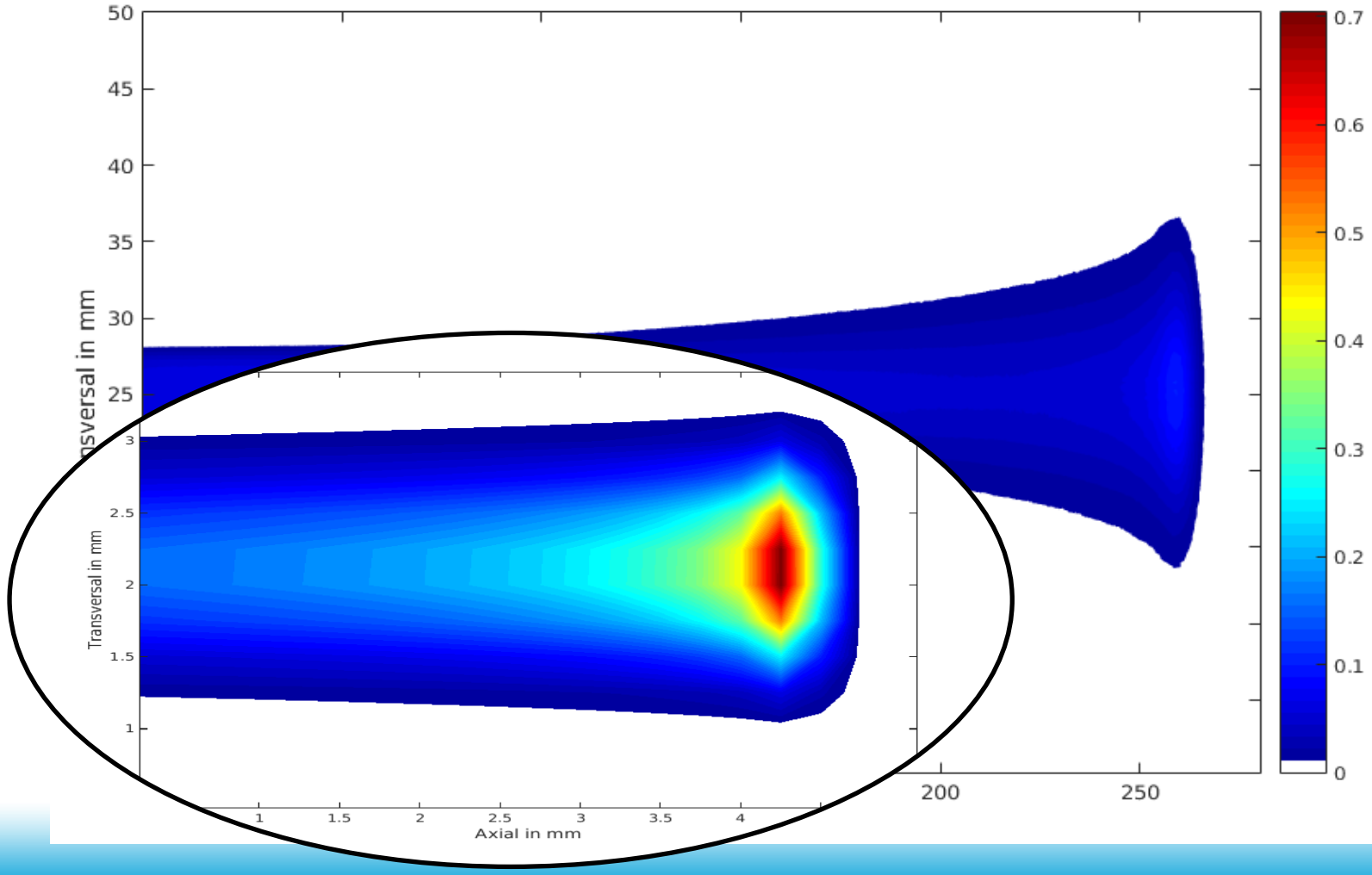
simulation vs exp



B.E. Treeby, B.T. Cox, J. Biomed. Opt., vol. 15, no. 2, p. 021314, 2010.

From 20 to 200 MeV, what do we expect

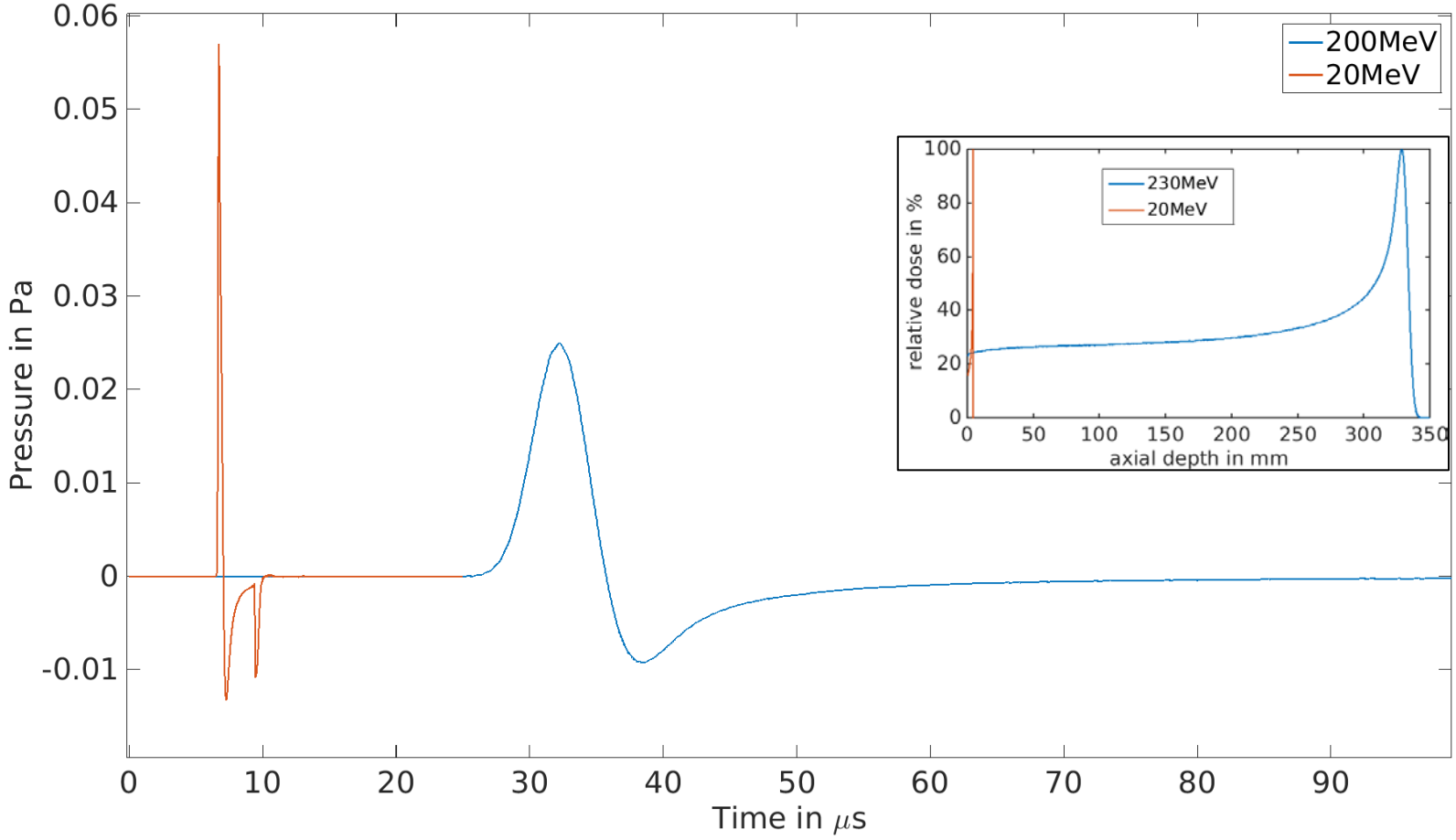
Dose from Geant4



Dose in G

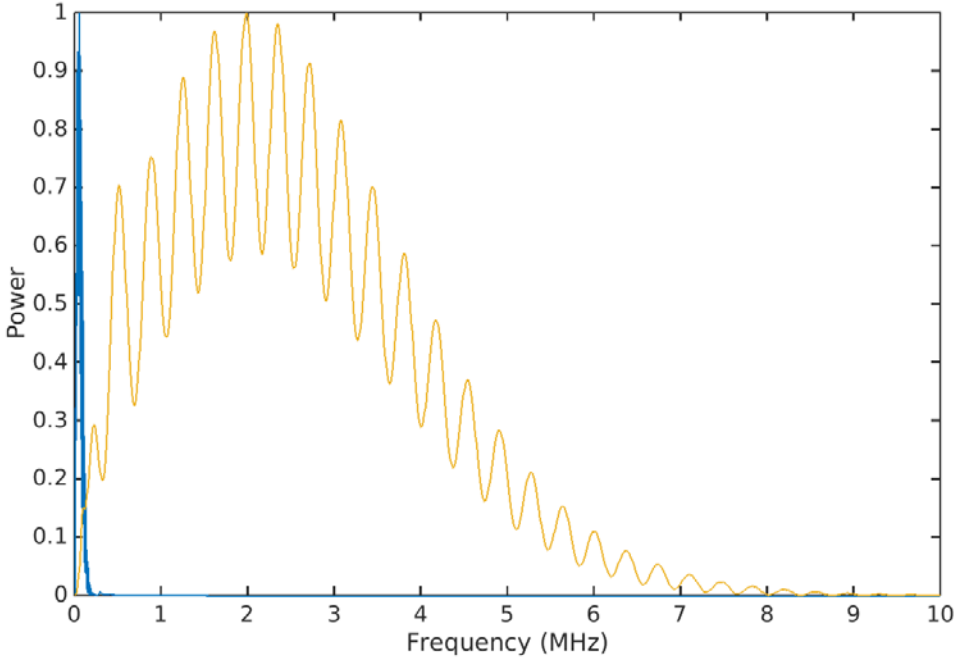
Simulation 50ns

Simulation 20MeV and 200MeV, 50 ns FWHM Gaussian proton pulse

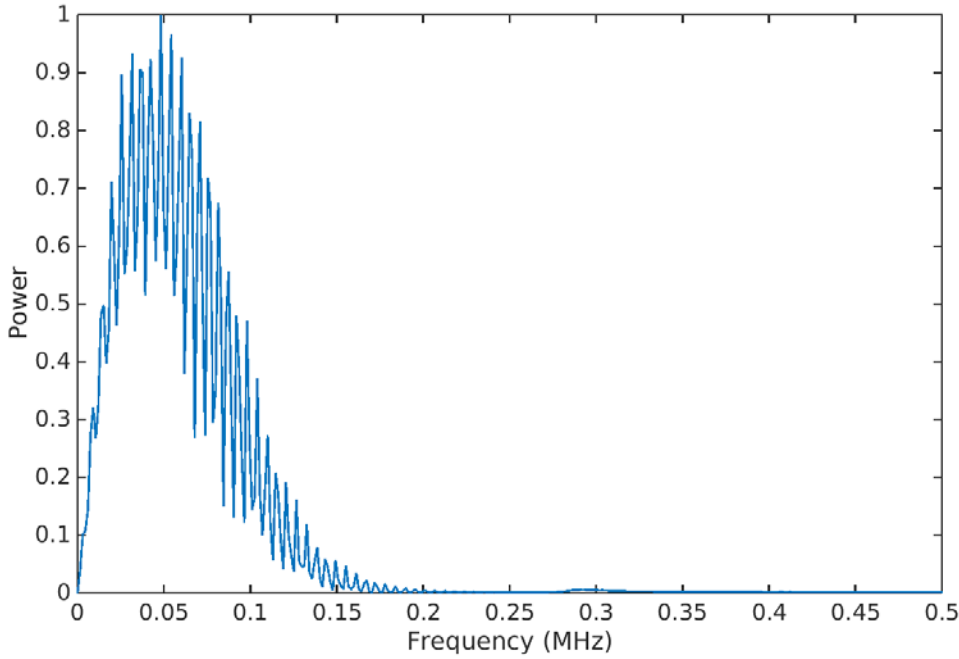


Frequency spectrum

20 MeV



200 MeV



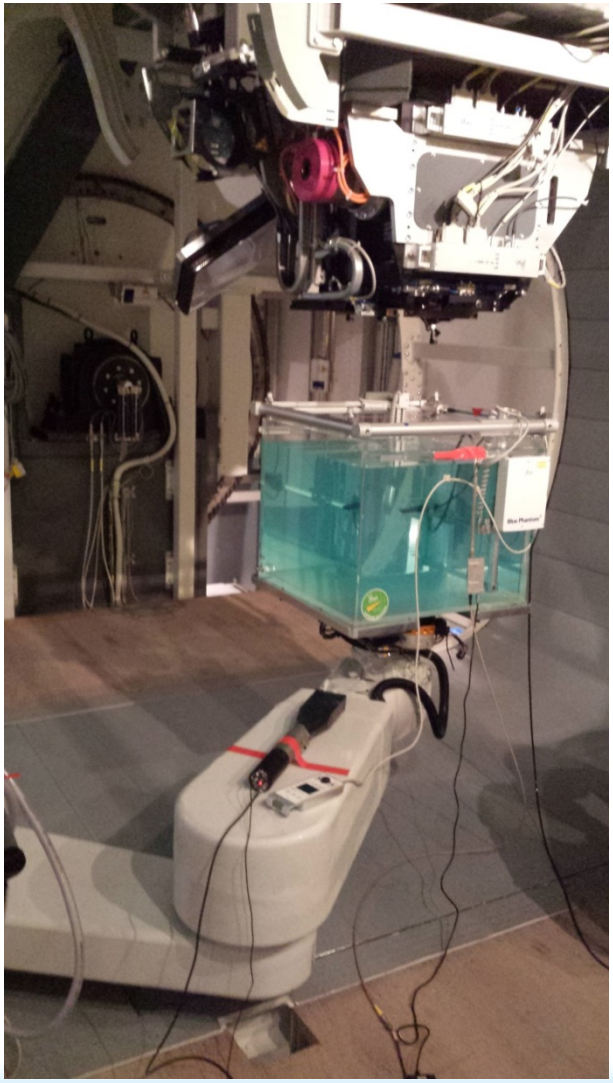
Measurements in Nice April 2015

Nice Centre Lacassagne (commissioning phase)

syncro-cyclotron

- 6-7µs FMHW per pulse
- ~ 5pc/pulse, 1kHz repetition

In collaboration with iba



Summary
Measurements in Nice

- We were able to detect the ionoacoustic signal from a 230MeV proton beam, but technical improvements need to be done to further reduce noise and distortions
- Nevertheless, we were able to measure
  - The shift of the range in water induced by a 1MeV change in beam energy and constant detector position
  - The temporal shift of the signal induced by mm movements of the detector with constant beam energy

Summary
Measurements in Nice

- The overall average of the measurements is in very good agreement with Geant4 simulations, but the precision is not yet satisfying
- Improvements in the experimental setup and preparations were made, from which we can expect a reproducibility below ±1mm of the range measurements in an upcoming beam time

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Conclusion & Outlook

- Data analysis on 20MeV Ionoacoustics measurements allowed a range verification with a reproducibility within 50µm difference to Geant4 simulations
- Confirmation of Ionoacoustics at clinical energies as seen in k-Wave simulations, the mean is in good agreement to Geant4 simulations with a precision of 1-2 mm, but will be improved with better trigger
- Presented results substantiate Ionoacoustics to be a simple, fast and direct method for range verification, but SNR remains a major challenge.

Acknowledgement

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  - S. Kellnberger, M. Omar, V. Ntziachristos
- **IBA**
  - F. Vander Stappen, J. Van de Walle, S. Henrotin, B. Reynders, D. Bertrand, D. Prieels
- **Coworkers and Colleagues of our medical physics Department**

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