

PAUL SCHERRER INSTITUT



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# On-line dynamic beam intensity control in a proton therapy cyclotron

22<sup>nd</sup> International conference on cyclotrons and their application, 24.09.2019



# Proton therapy and beam intensity control

# Proton therapy and pencil beam scanning (PBS)

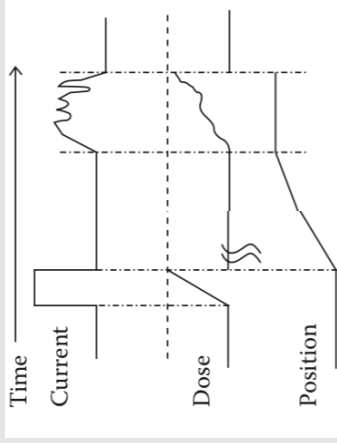
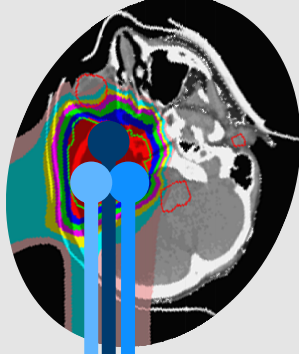
Cyclotron



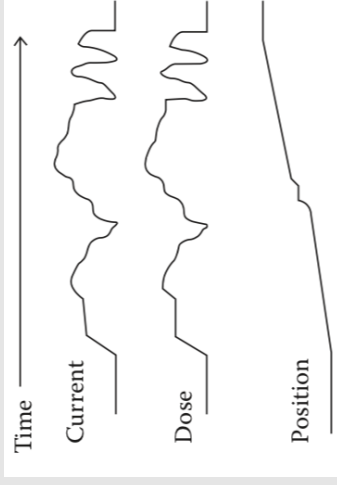
Energy switching system



Scanning  
Dose monitoring



Spot scanning (standard)

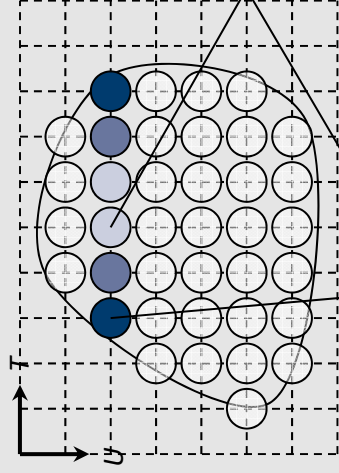


Continuous scanning (new)

Continuous scanning:  
faster but requires high-precision control of beam current intensity

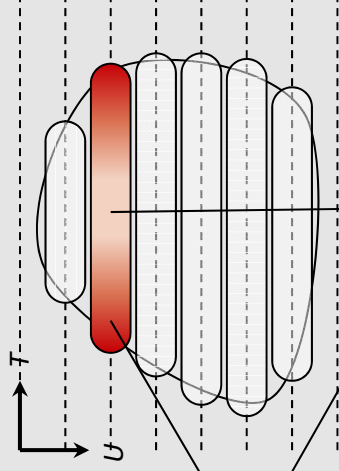
# Continuous line scanning: control requirements

## discrete spot scanning



high dose

## continuous line scanning

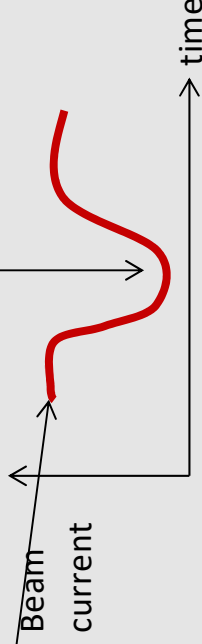


low dose

## Beam intensity control requirements for CLS:

- *Fast settling time*  
( $< 750 \mu\text{s}$  at PSI)
- *Integral dose precision*  
( $< 2\%$  at PSI)

Tolerances from  
Klimpki, G. et al.  
(2017) *ICALPCS2017*,  
paper THCPA06.





Continuous line scanning: PSI implementation

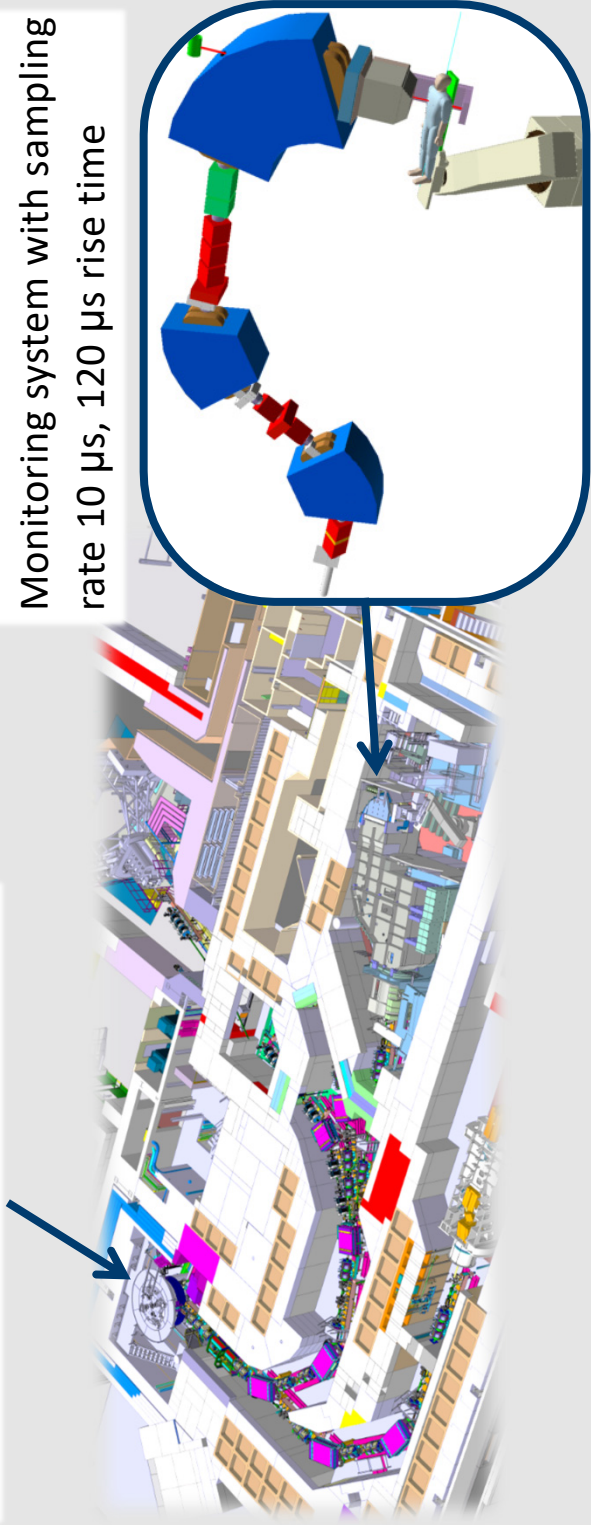
# The PROScan beam line and Gantry 2

## COMET cyclotron:

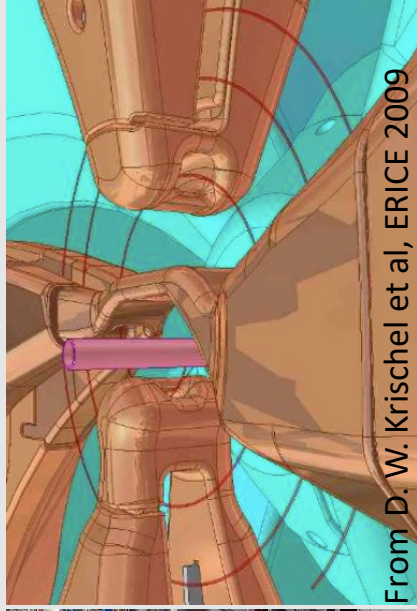
Active control of beam intensity

## Gantry 2:

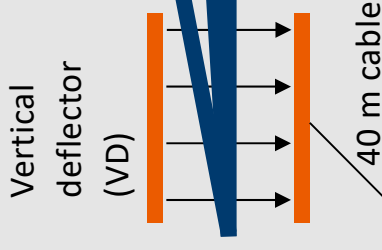
Monitoring system with sampling rate  $10 \mu\text{s}$ ,  $120 \mu\text{s}$  rise time



# COMET cyclotron and beam intensity modulation

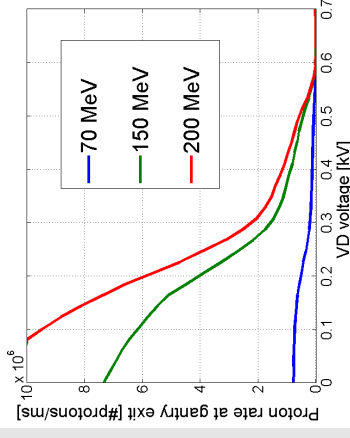


From D. W. Krischel et al, ERICE 2009

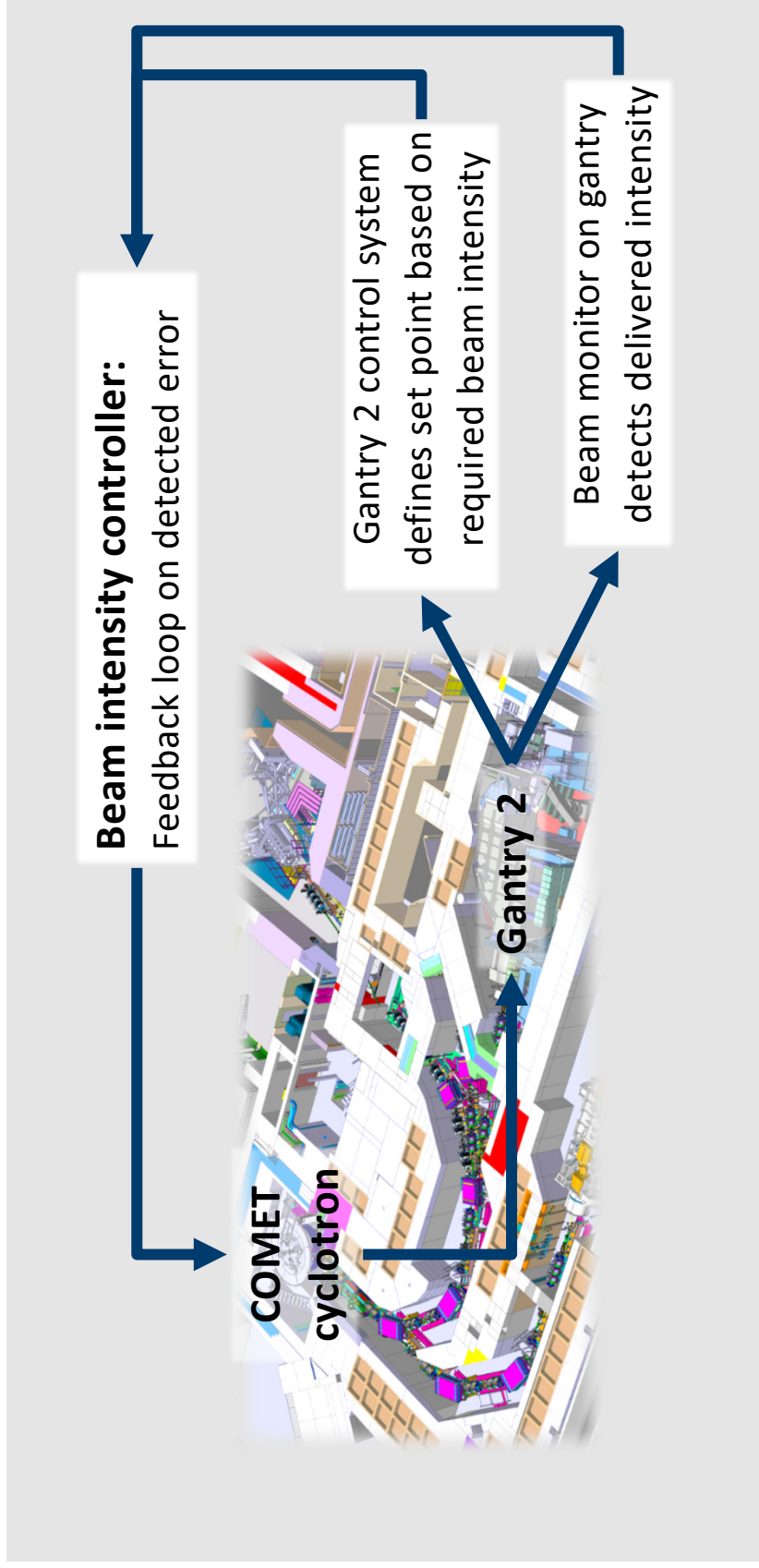


- Superconducting cyclotron (ACCEL/Varian)
- 250 MeV extracted beam, 24/7 operation
- Constant beam extracted from ion source
- Beam intensity modulated with internal vertical electrostatic deflector

Power supply:  
HV ~ 0 kV



# Beam intensity controller for continuous line scanning at PSI Gantry 2

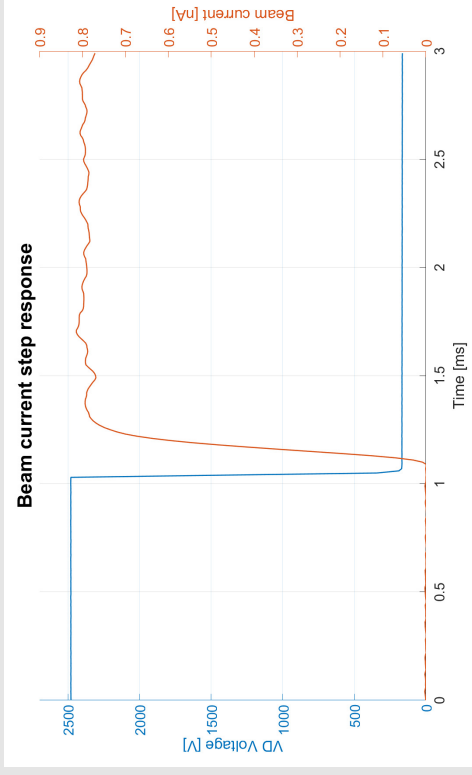


# Challenges: reaction times

V. Minnig, master thesis, EPFL

Large reaction time caused by delays  
(communication, acceleration etc) and  
collection time of monitoring ionization  
chamber

***200  $\mu$ s delay***



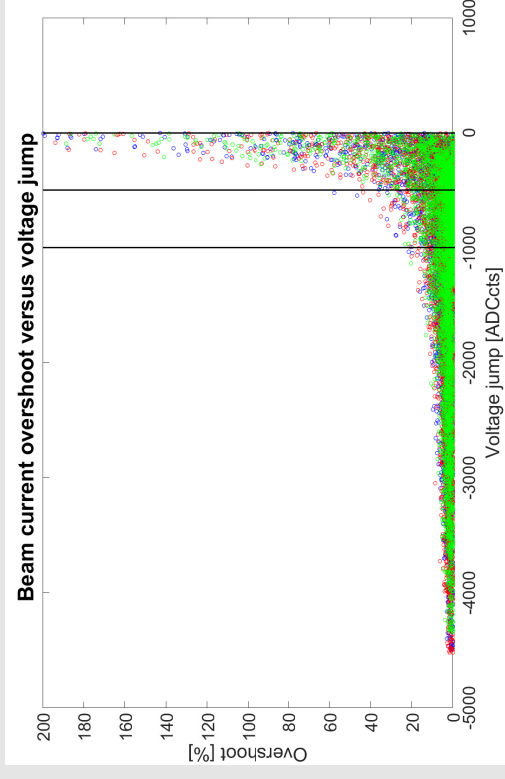
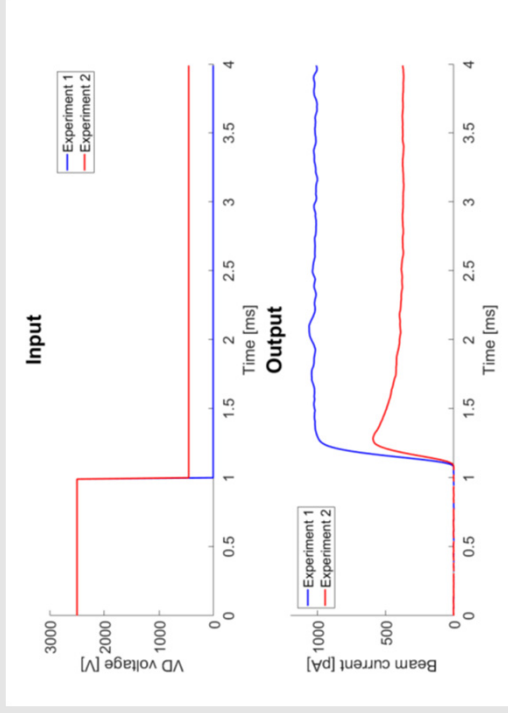
Power supply located outside bunker

System capacitance: 5 nF

Almost all coming from cable to VD!  
Limitation in reaction time of power  
supply

# Challenges: power supply

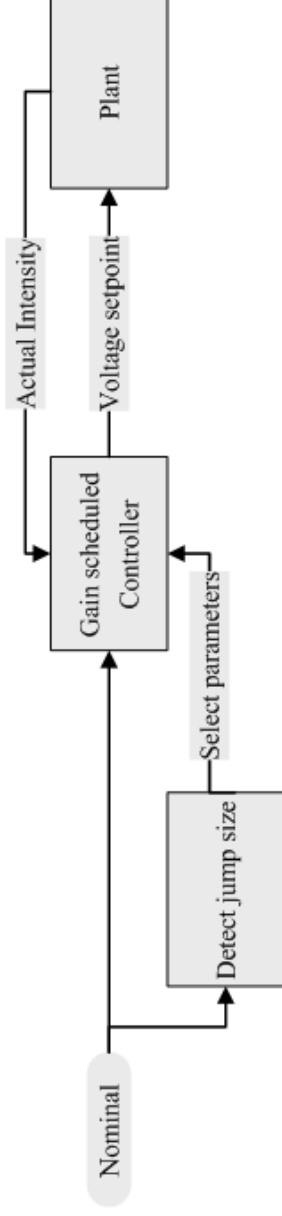
V. Minnig, master thesis, EPFL  
 P. Fernandez Carmona et al. (2018)  
*Proc. PCaPAC'18*, paper FRCC2



- Overshoots due to power supply internal stages, large variability
- Controller can be more aggressive (= faster) when expected overshoot variability is small, more robust (= slower) when expected overshoot variability is large



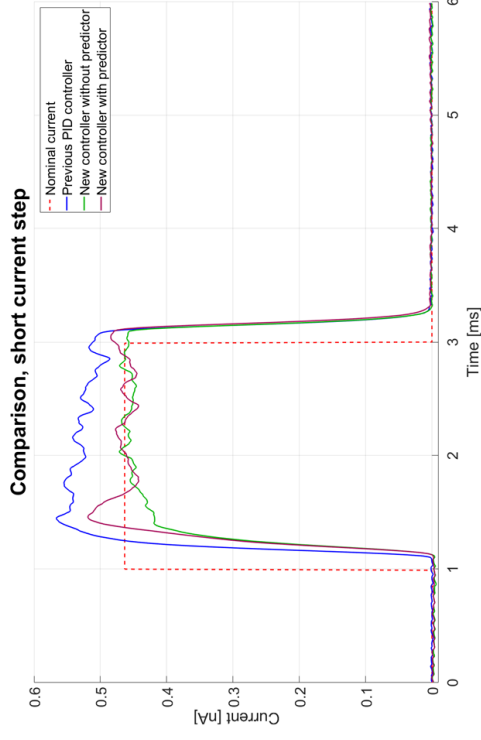
## Controller design and results



Controller parameters chosen according to jump size (and expected variability)

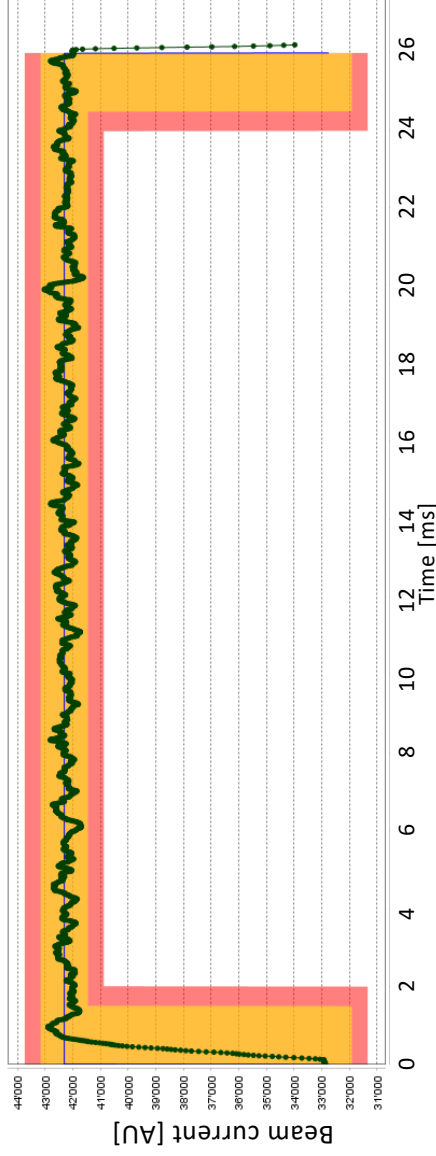
Monitoring system reaction times dominate speed of response

Smith predictor to compensate dead time

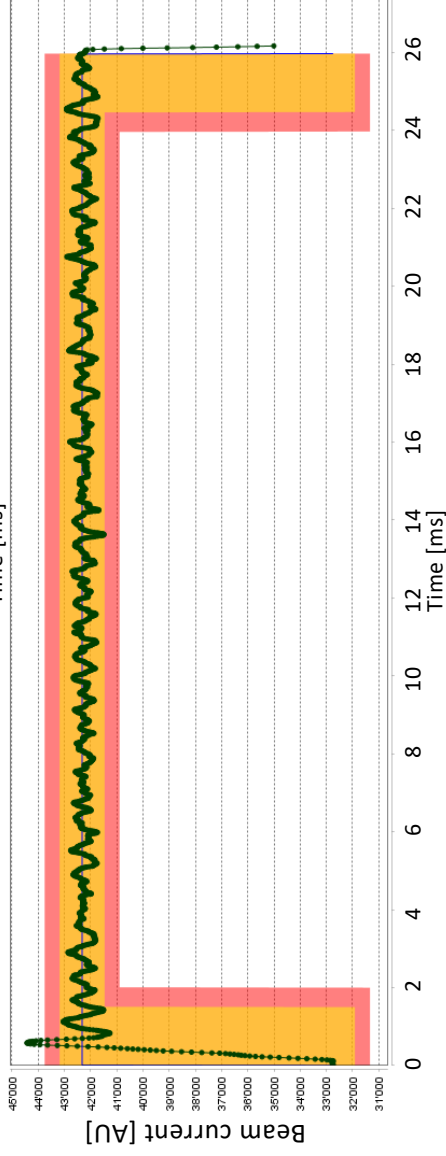


# Sensitiveness to cyclotron conditions

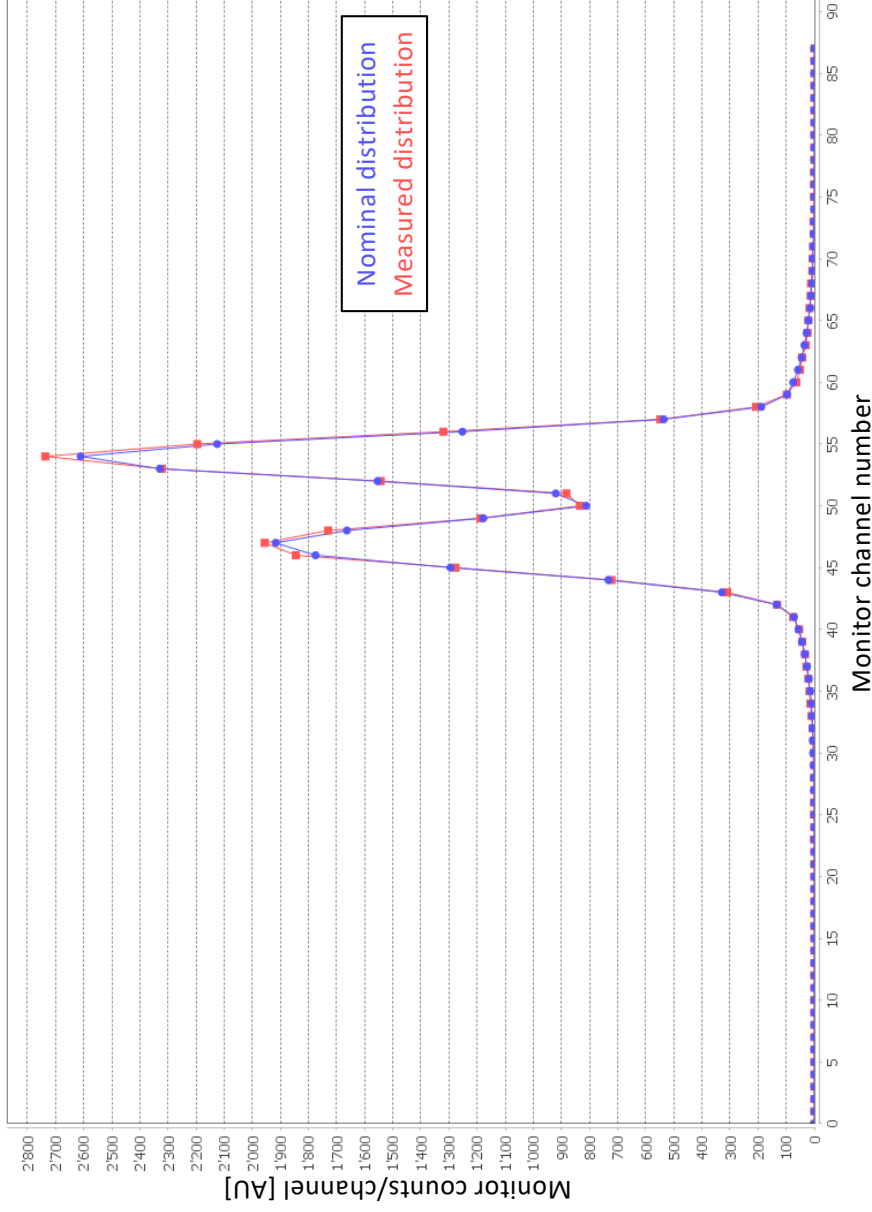
Same patient field,  
measured at 1h  
distance



Cyclotron output  
variations can cause  
controller to work in  
unstable regions –  
more robust controller  
parameters chosen for  
final implementation



# Integral dose distribution precision



Comparison of integral dose distributed at the measured at the patient

Convolution of beam intensity, scanning pattern and beam size

# Conclusions

- ***Continuous Line Scanning requires high-precision control of beam intensity***
- Beam intensity control at the COMET cyclotron and Gantry 2:
  - ***Vertical Deflector inside the cyclotron used for fast beam modulation***
  - Challenge of the setup: cope with PS overshoot and limited monitor reaction time using a ***robust gain-scheduled controller with Smith predictor***
- Future steps:
  - Assessment of controller performance with clinical cases
  - Investigation of different options for power supply internal regulation (reduce overshoots) to further improve precision for clinical commissioning

# Acknowledgements

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G. Klimpki, V. Minnig
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