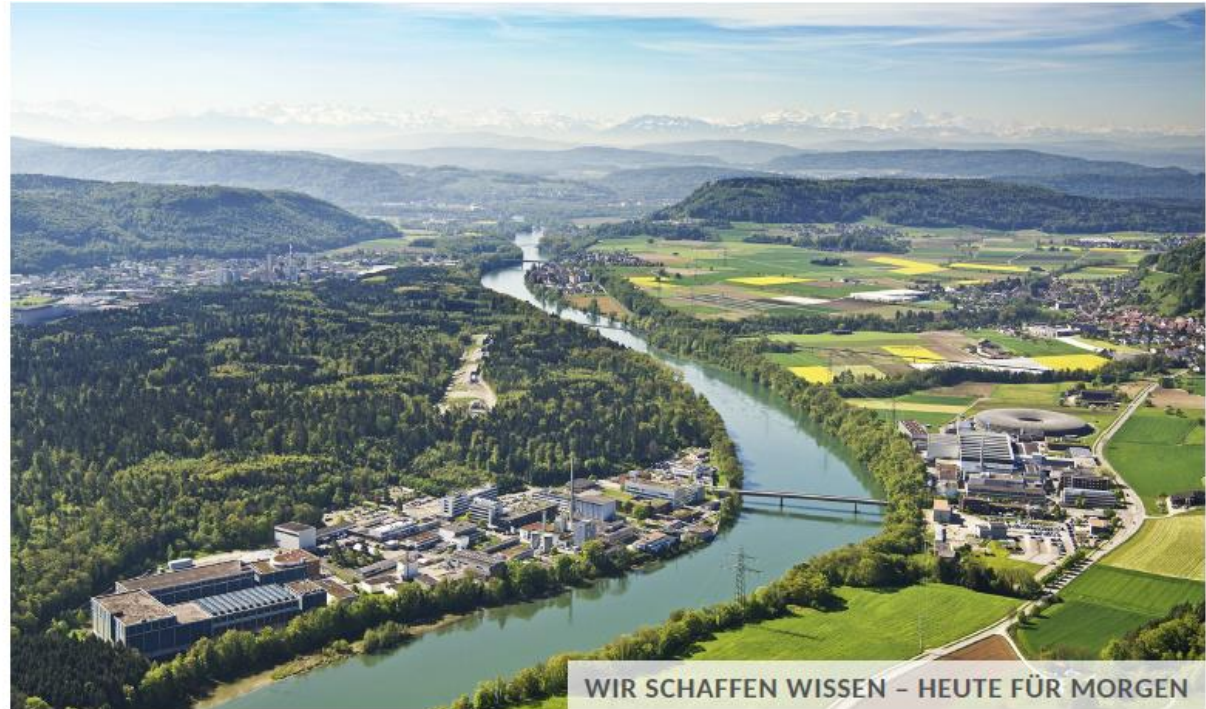


PAUL SCHERRER INSTITUT



Tony Lomax :: Head of Medical Physics :: Paul Scherrer Institute

## Dose delivery

International Conference on Medical Accelerators and Particle Therapy –  
4-6<sup>th</sup> September 2019

# Overview of presentation

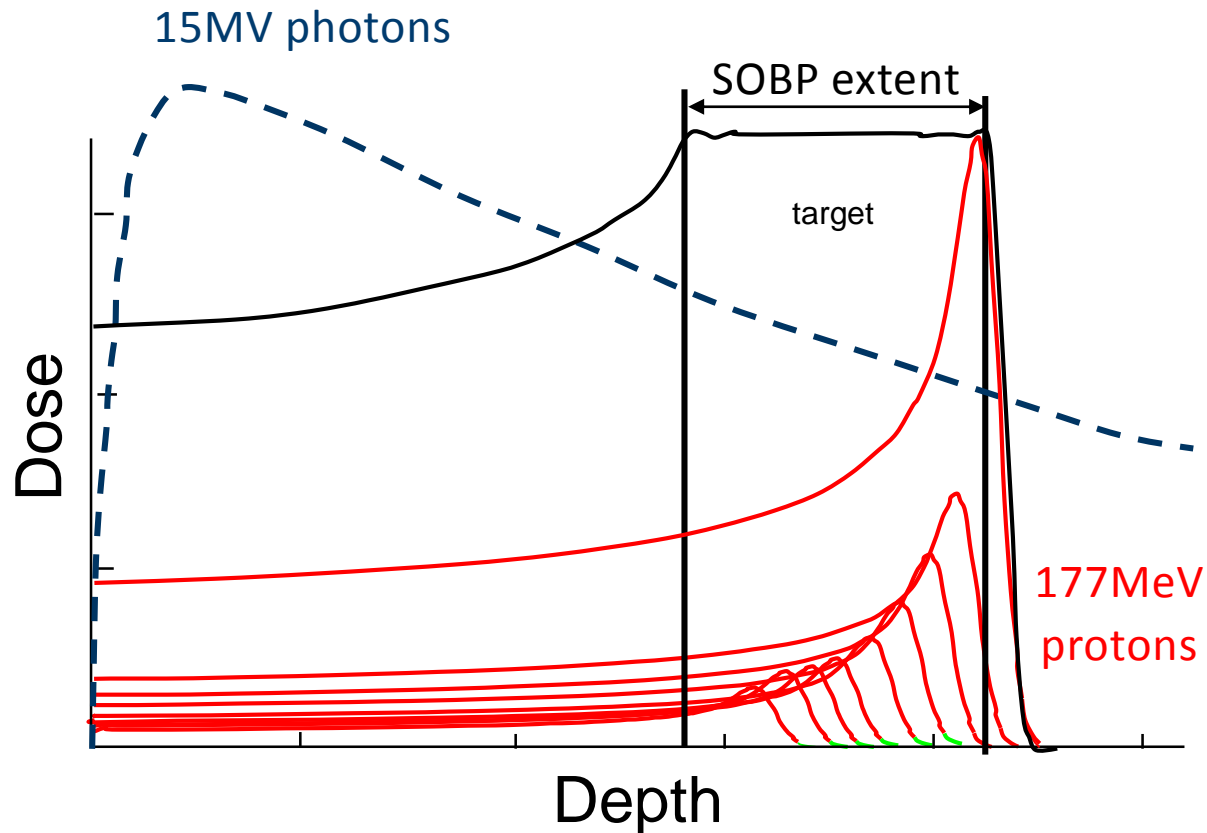
1. Proton therapy and its delivery
2. Improving lateral penumbra
3. Reducing treatment times
4. Protons for FLASH?
5. Summary

# Overview of presentation

1. Proton therapy and its delivery
2. Improving lateral penumbra
3. Reducing treatment times
4. Protons for FLASH?
5. Summary

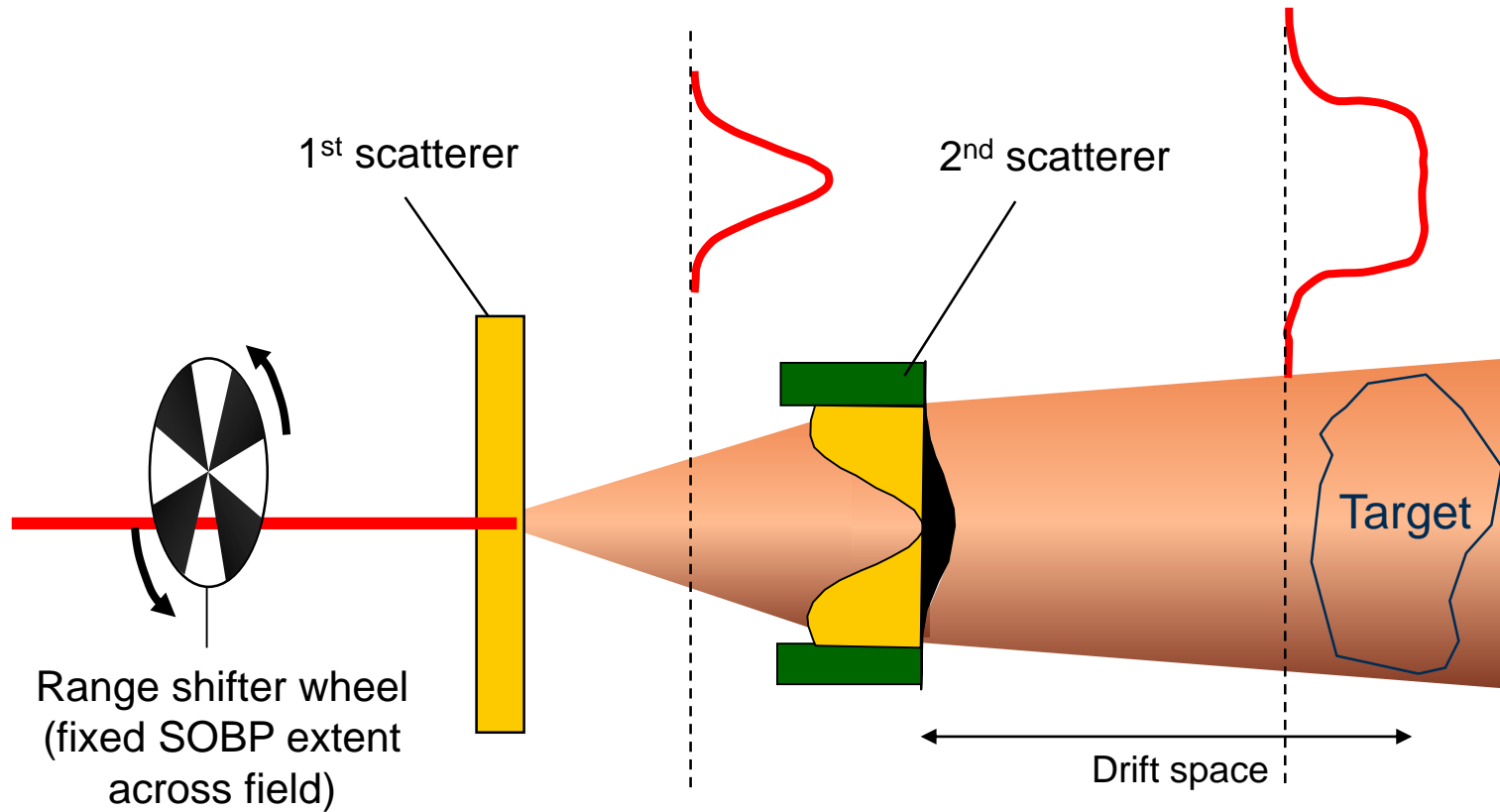
# Proton therapy and its delivery

## Why protons for cancer therapy?



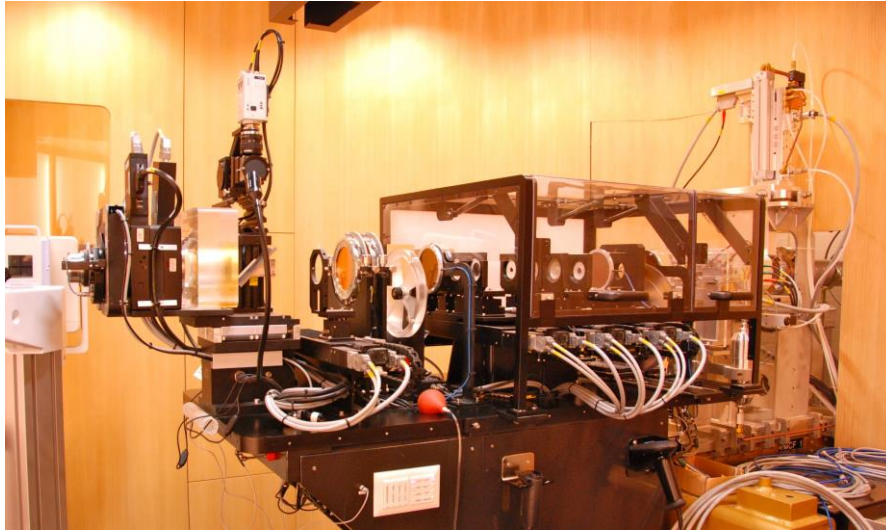
# Proton therapy and its delivery

## Making protons useful (1): Passive scattering

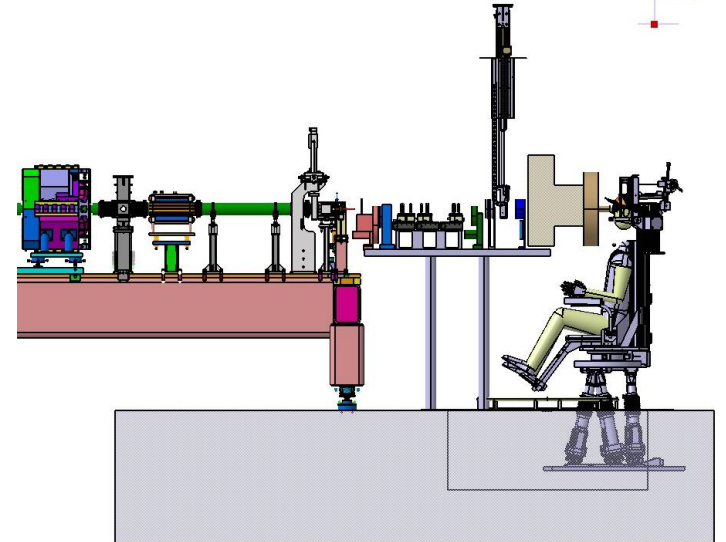


# Proton therapy and its delivery

## Passive scattering for ocular tumours – a success story

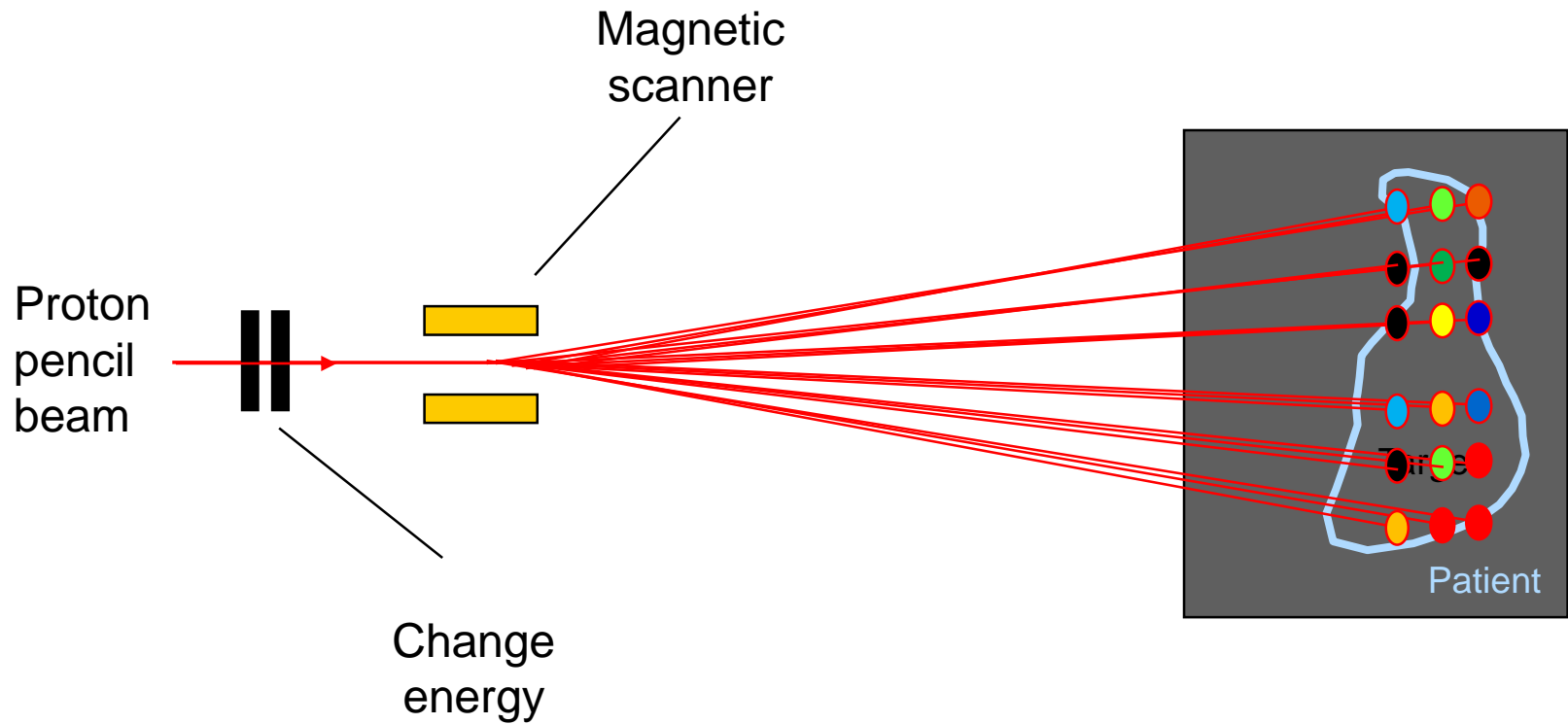


- Irradiation of eye tumors
- > 7000 patients treated @ PSI
- > 20% of all patients treated with proton world-wide
- *Tumor control rate of 98%*



# Proton therapy and its delivery

## Making protons useful (2): Pencil beam scanning

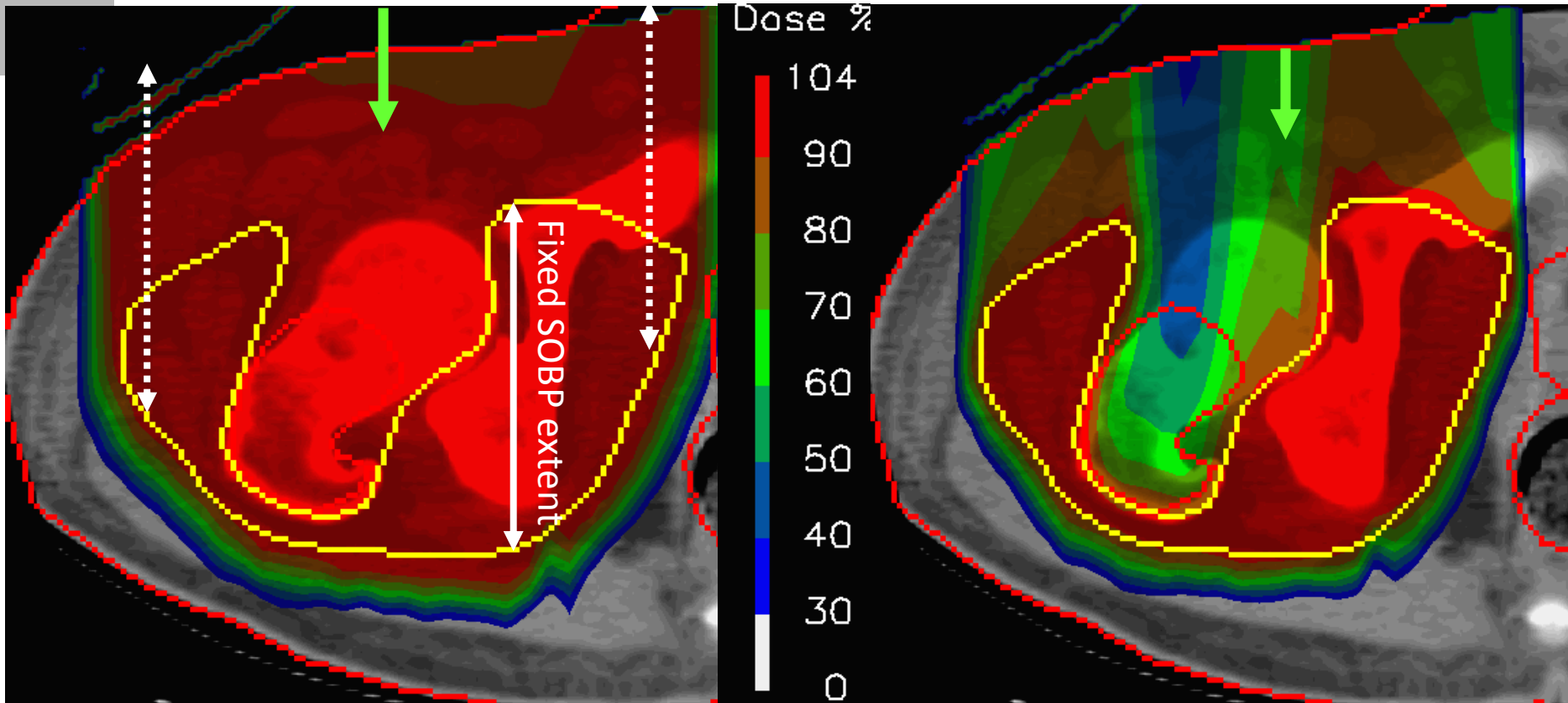


# Proton therapy and its delivery

## Passive scattering and Pencil beam scanning compared

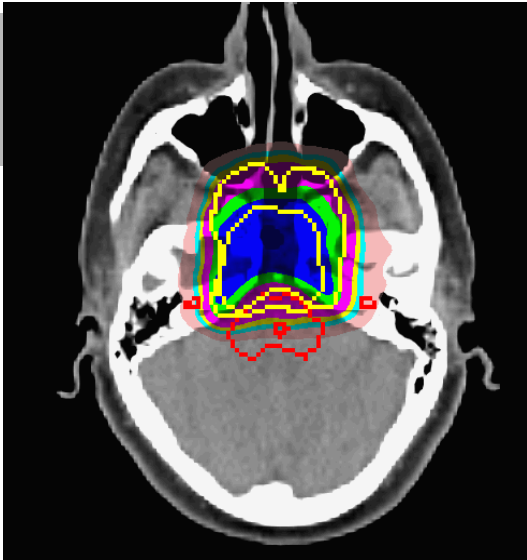
Passive scattering

Pencil beam scanning (PBS)



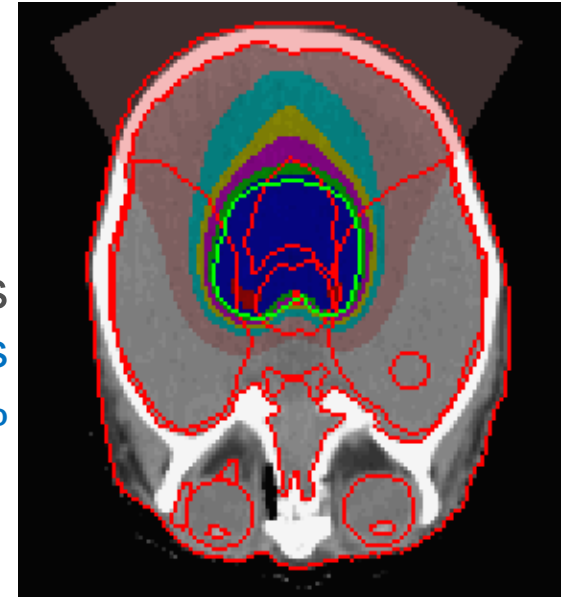


## The bottom line – Clinical results with PBS (PSI)

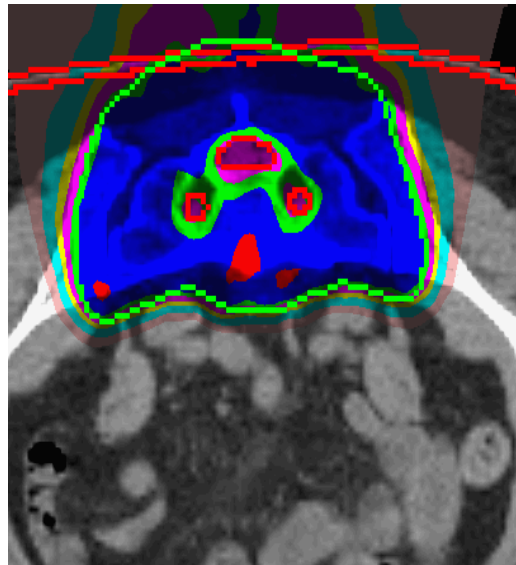


Skull base tumours  
222 Patients  
7y Local control: 80%

Ependymomas  
50 Patients  
5y Local control: 78%

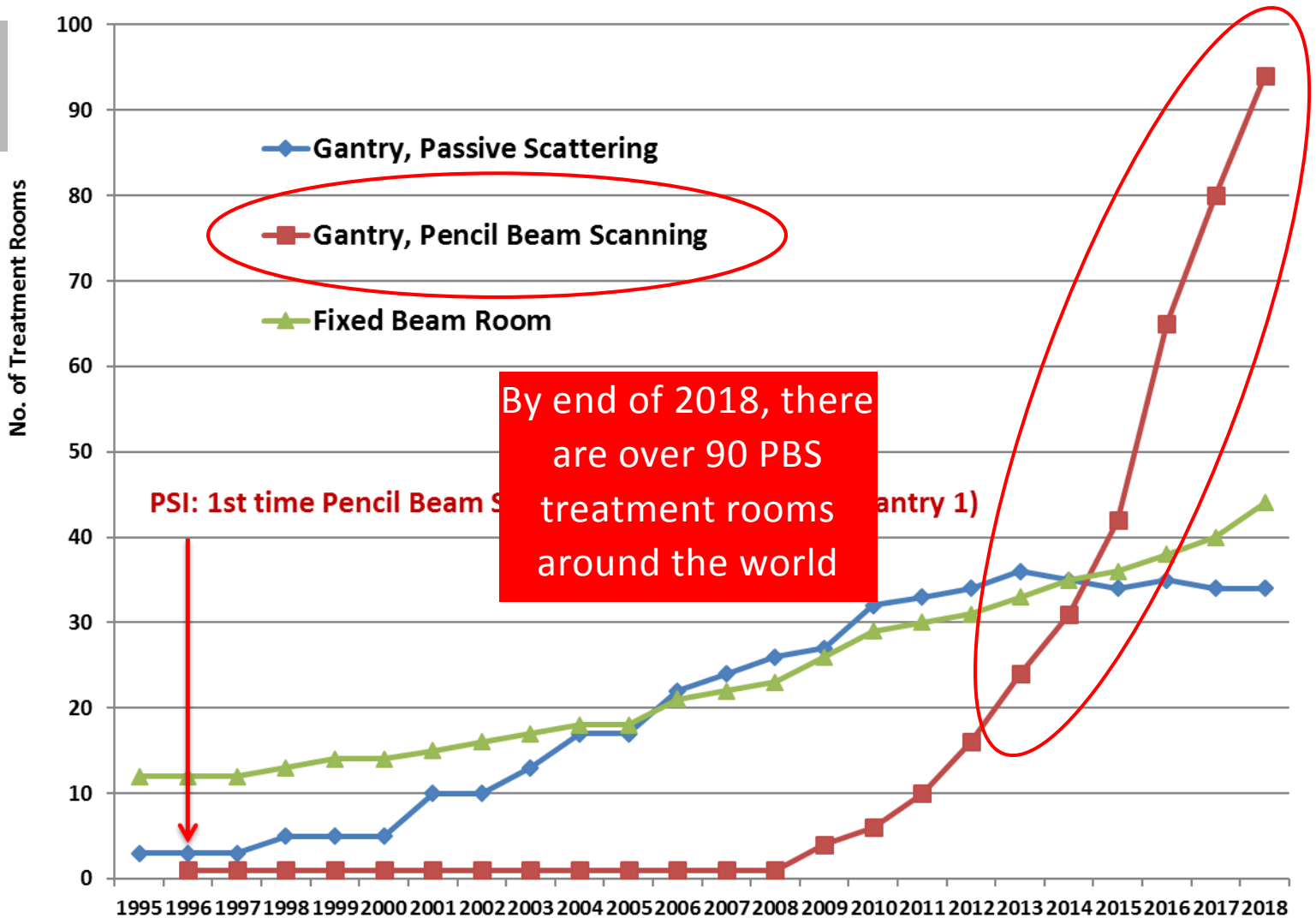


Sacral chordomas  
36 Patients  
5y Local control: 66%



# Proton therapy and its delivery

## The success of PBS



# Overview of presentation

1. Proton therapy and its delivery

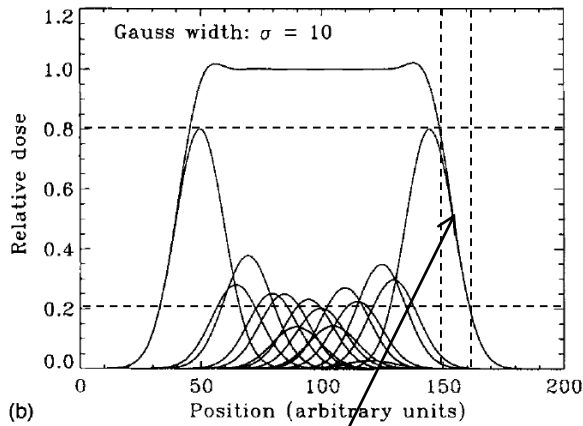
2. Improving lateral penumbra

3. Reducing treatment times

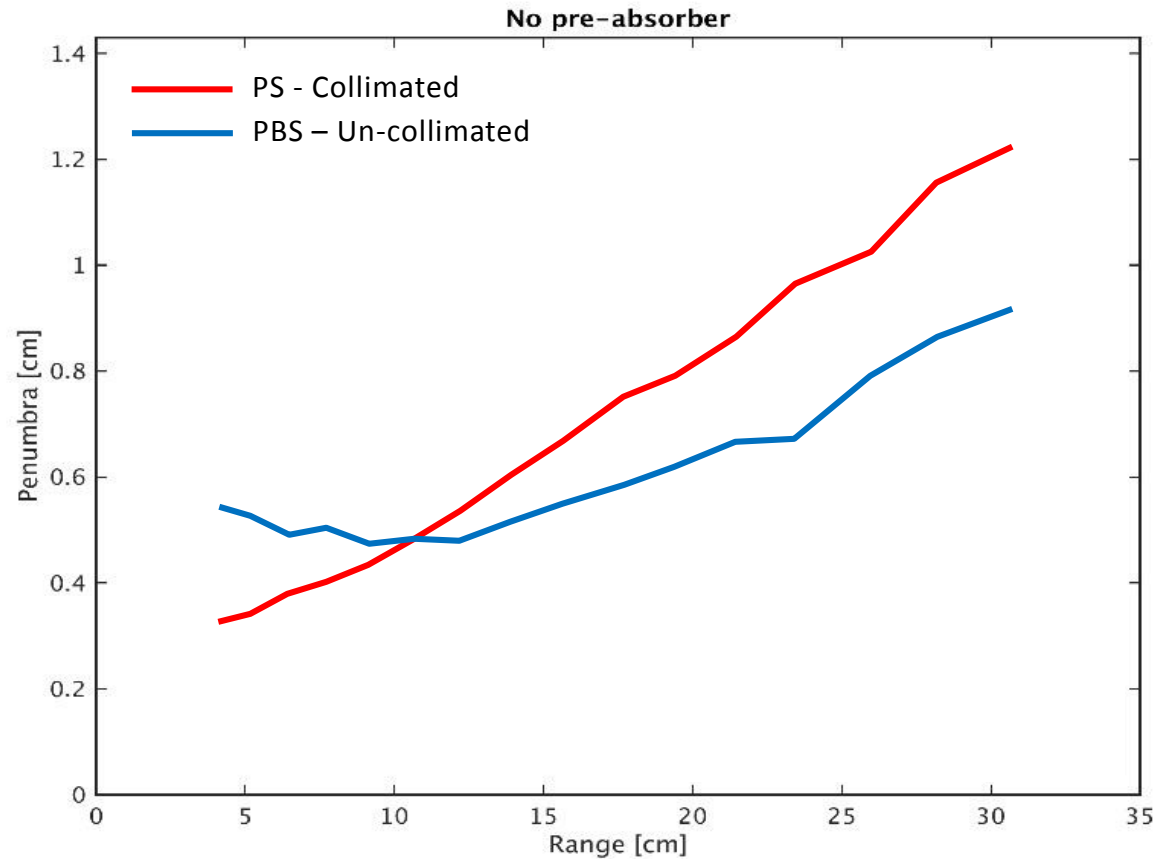
4. Protons for FLASH?

5. Summary

## Lateral penumbras for proton therapy

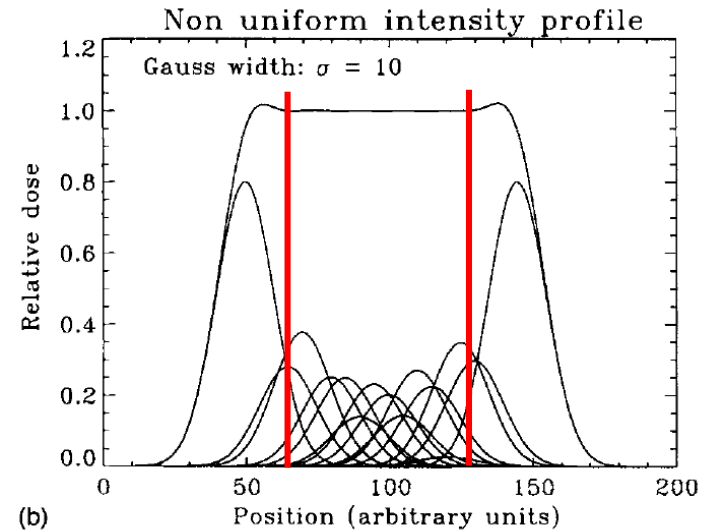
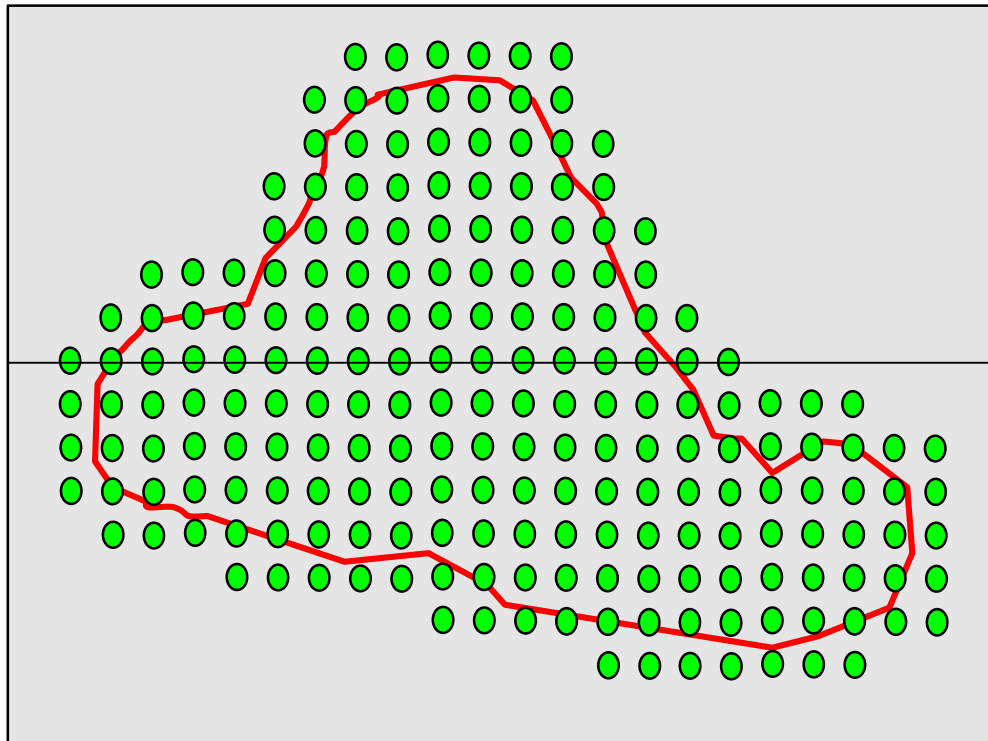


80-20%  
penumbra



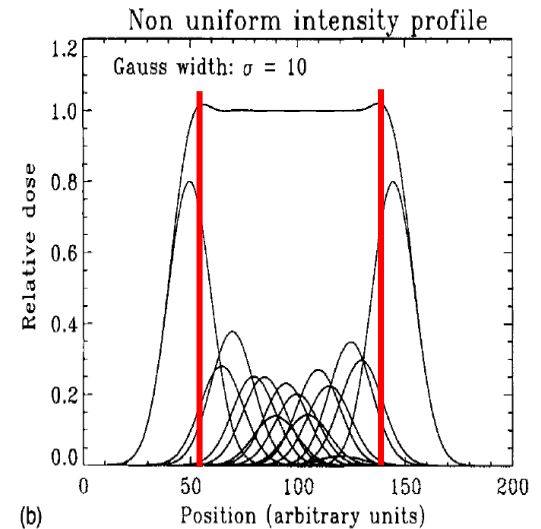
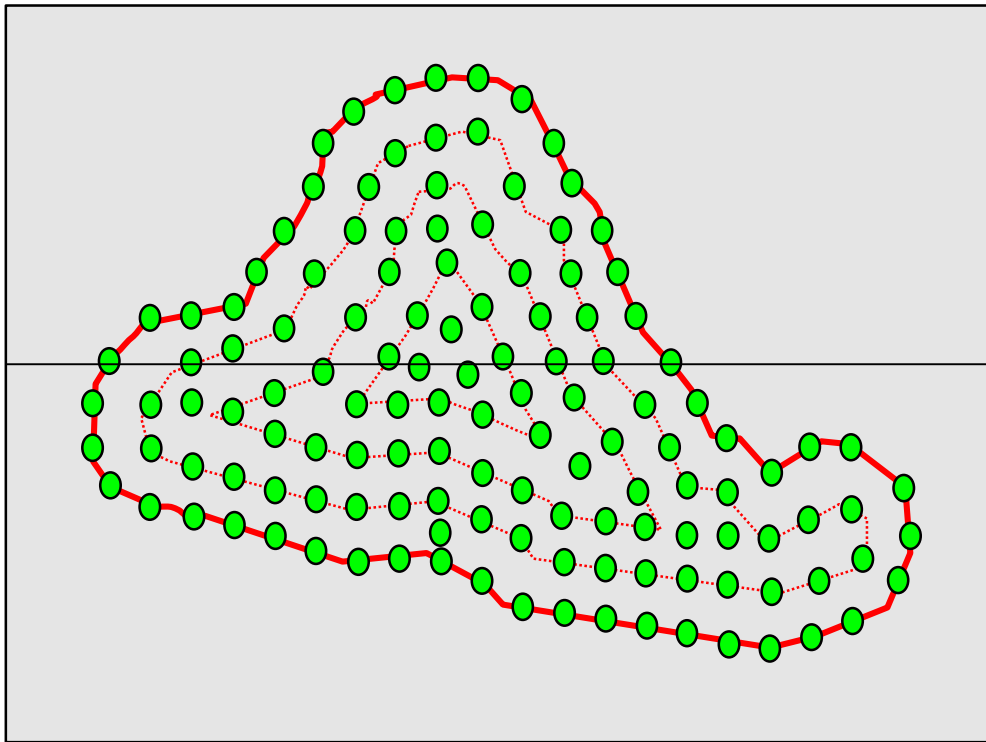
## Contour scanning

The conventional approach:  
Rectilinear scanning



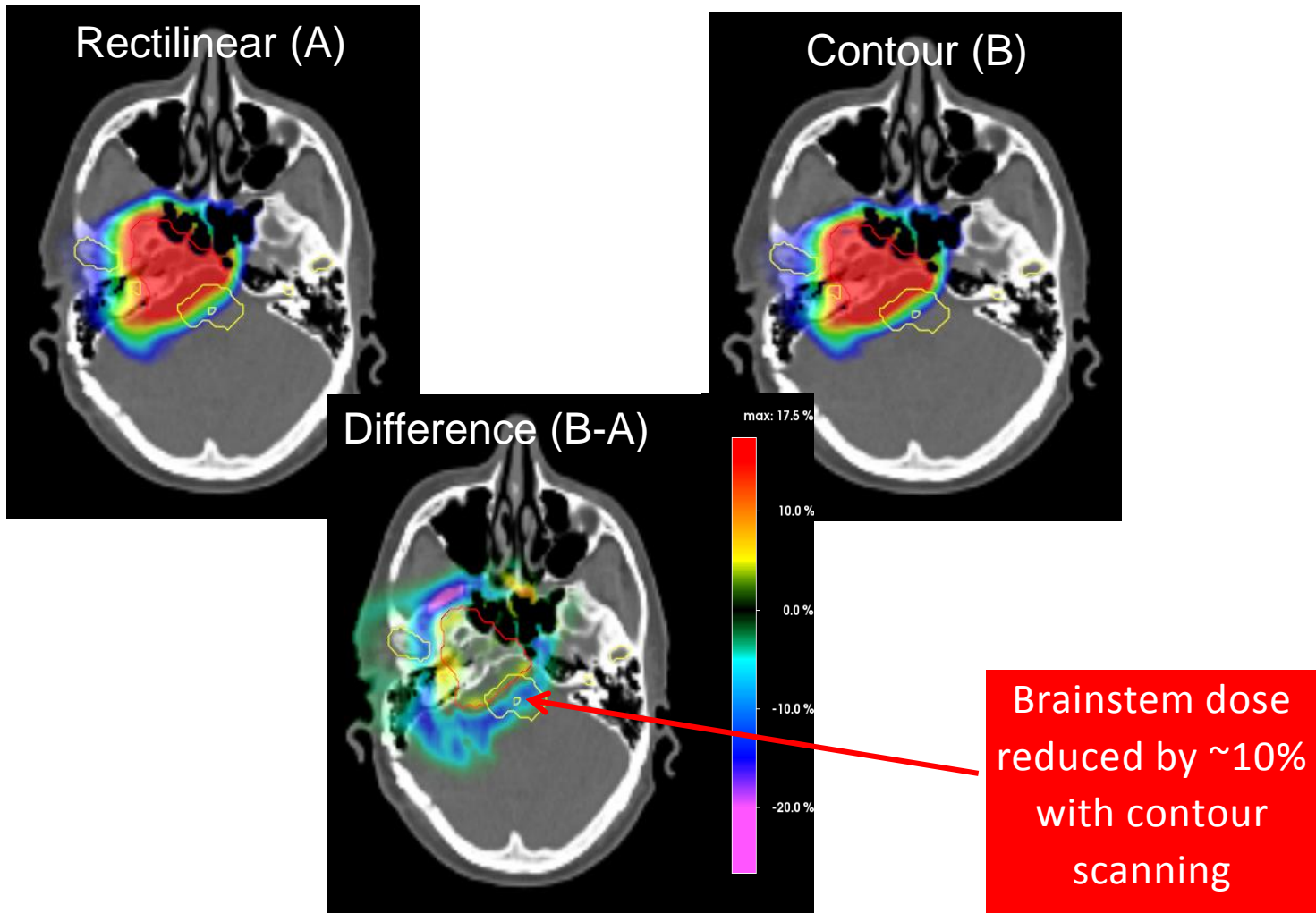
## Contour scanning

A more logical approach:  
Contour based

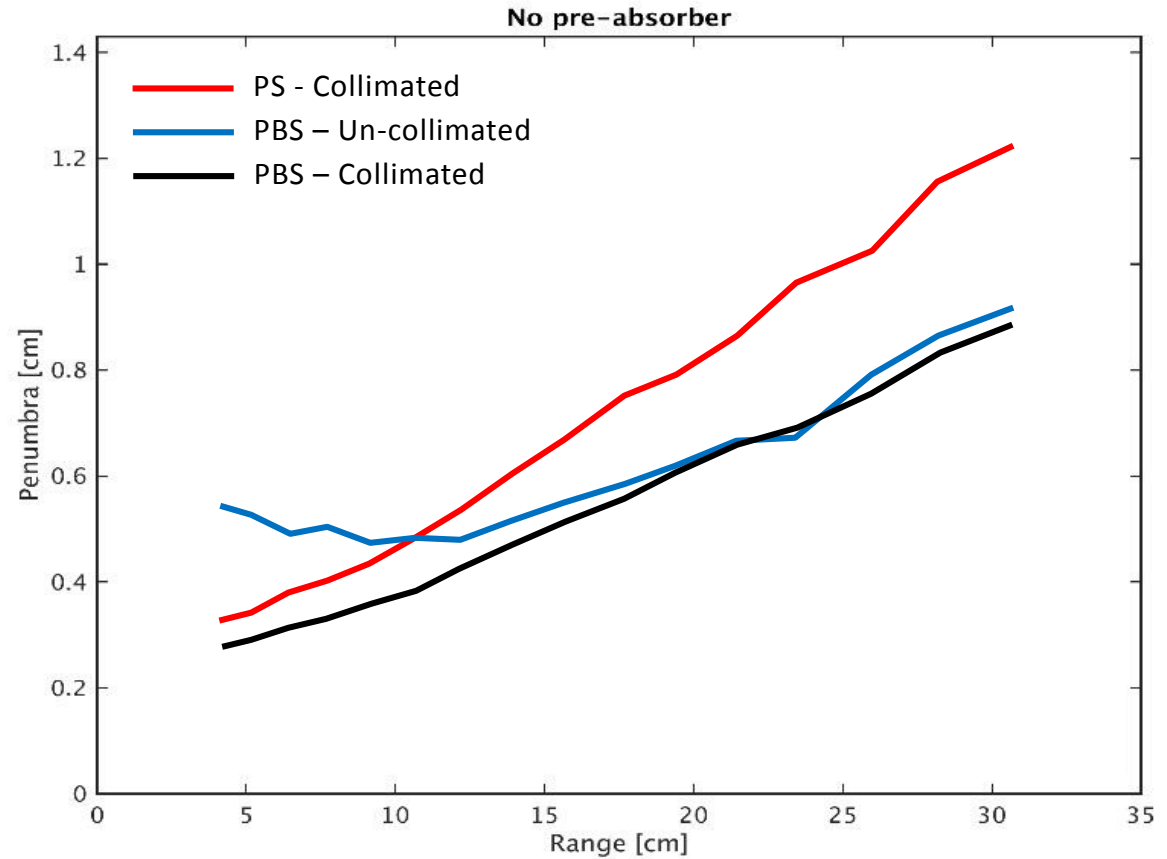
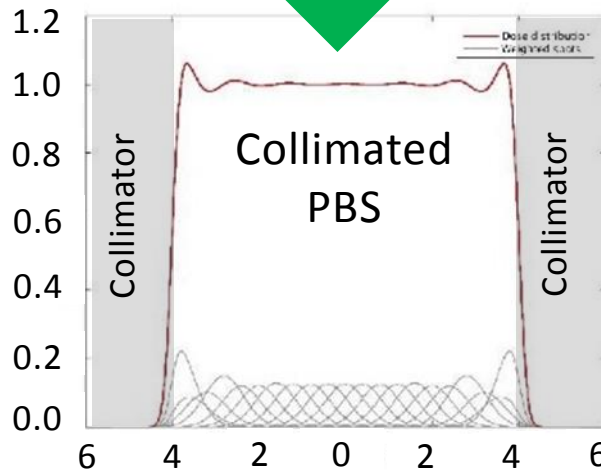
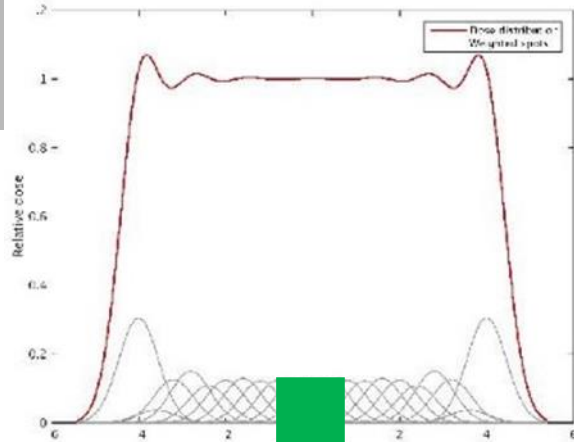


# Improving penumbra

## Contour scanning



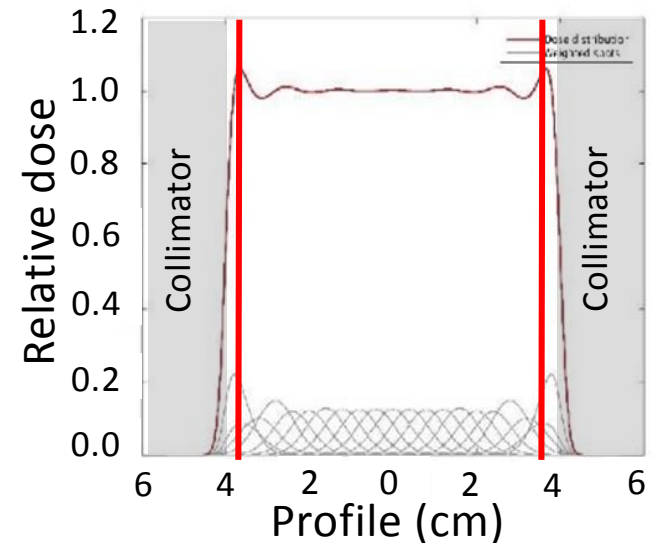
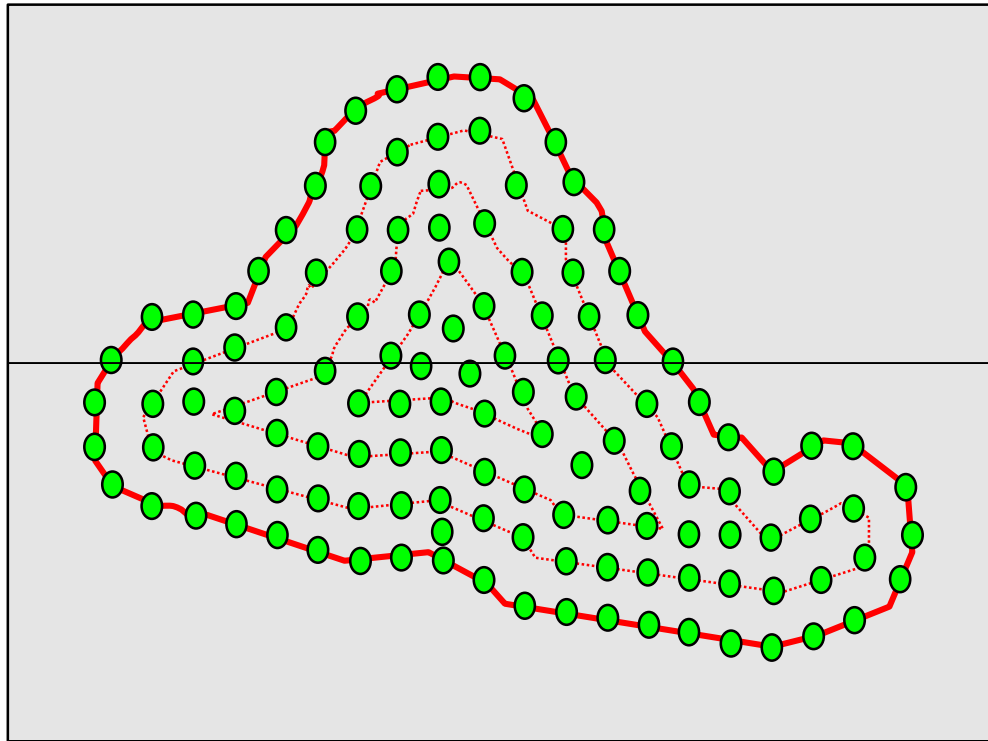
## Collimation for PBS proton therapy?





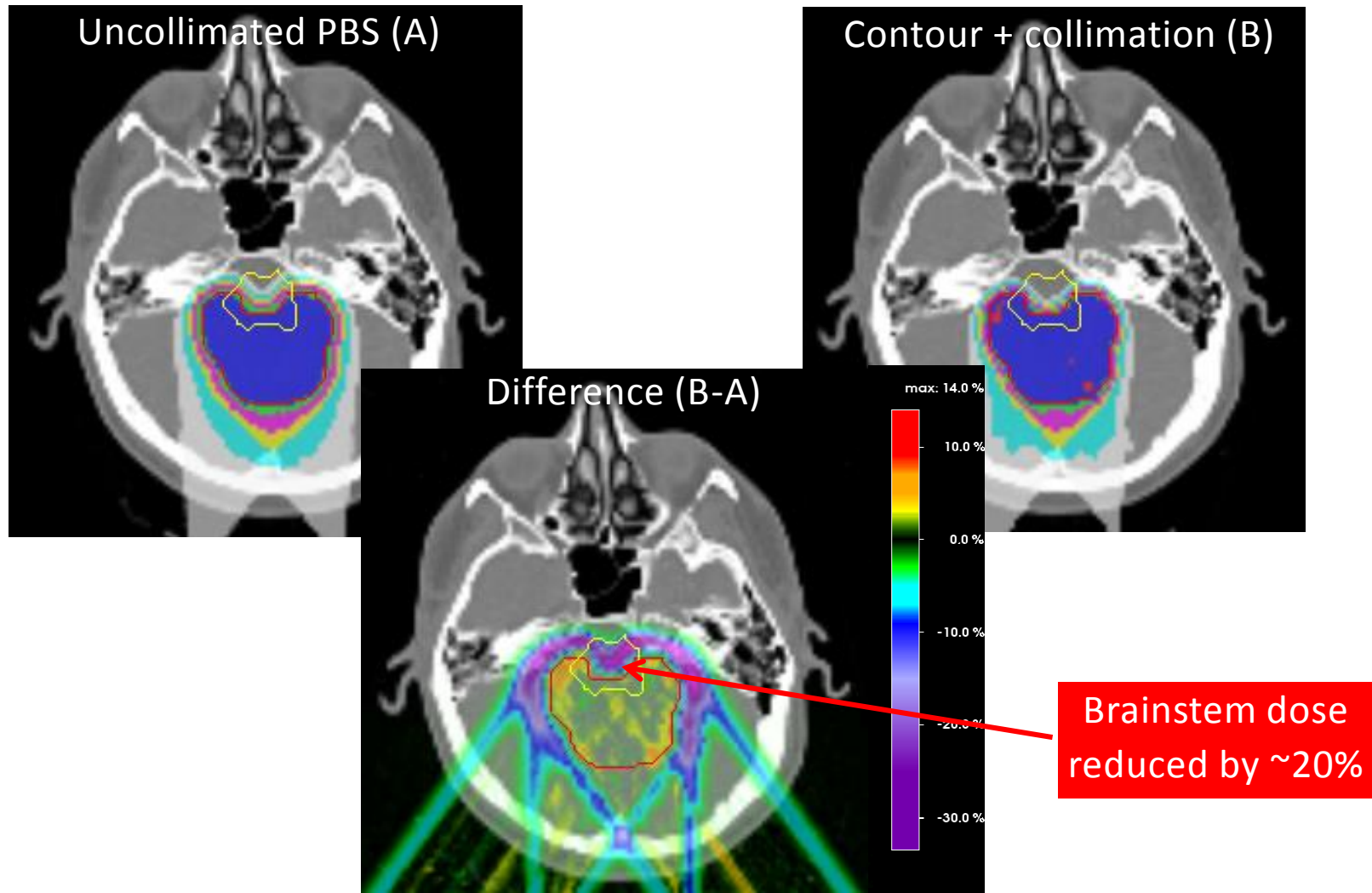
## Collimation for PBS proton therapy?

### Collimated contour scanning



# Improving penumbra

## Collimated (energy specific) contour scanning



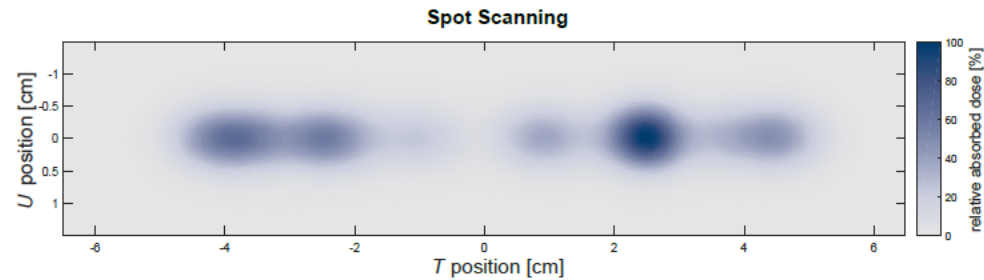
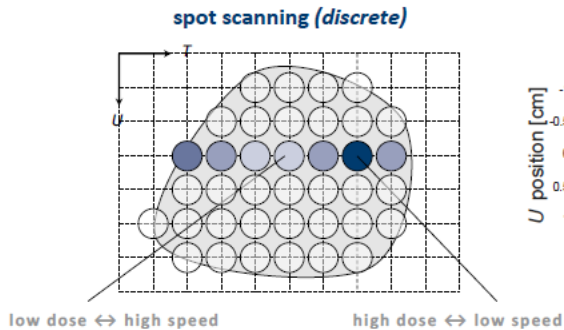
# Overview of presentation

1. Proton therapy and its delivery
2. Improving lateral penumbra
3. Reducing treatment times
4. Protons for FLASH?
5. Summary

# Reducing delivery times

E.g. Line/continuous scanning

Spot (discrete) scanning

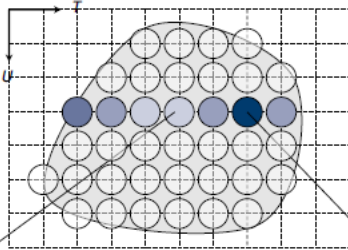


# Reducing delivery times

E.g. Line/continuous scanning

Spot (discrete) scanning

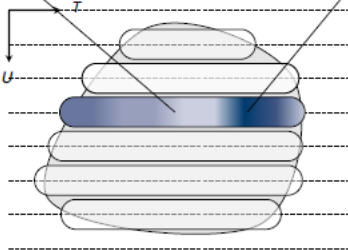
spot scanning (discrete)



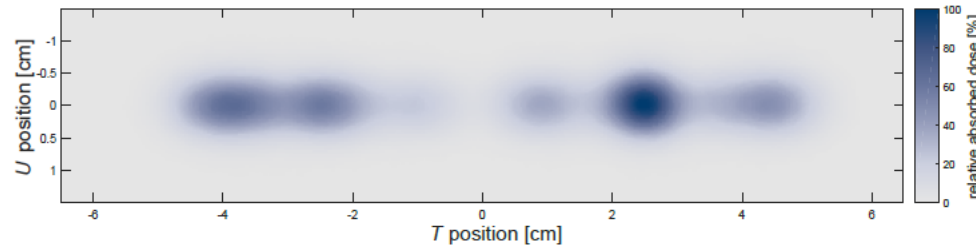
low dose ↔ high speed

high dose ↔ low speed

line scanning (continuous)

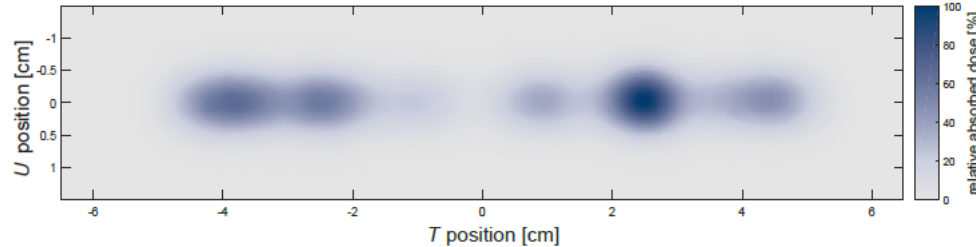


Spot Scanning



c.f. 'Step-and-shoot'

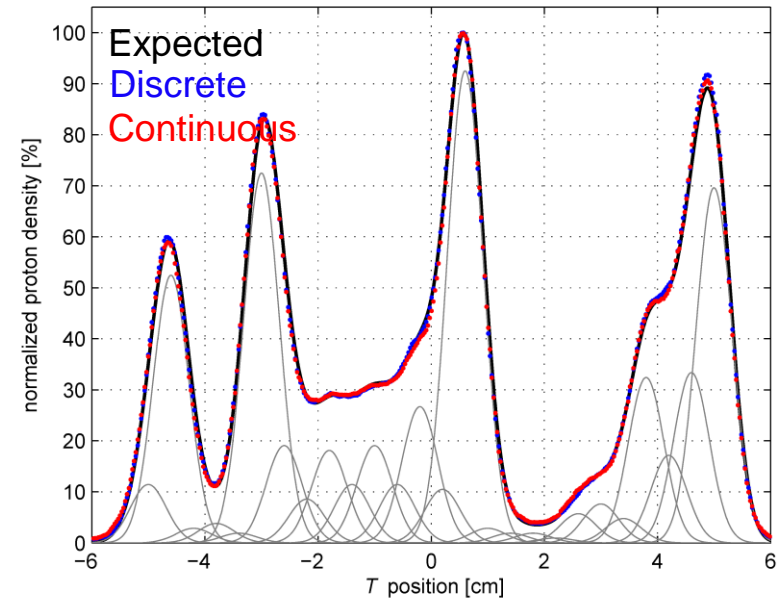
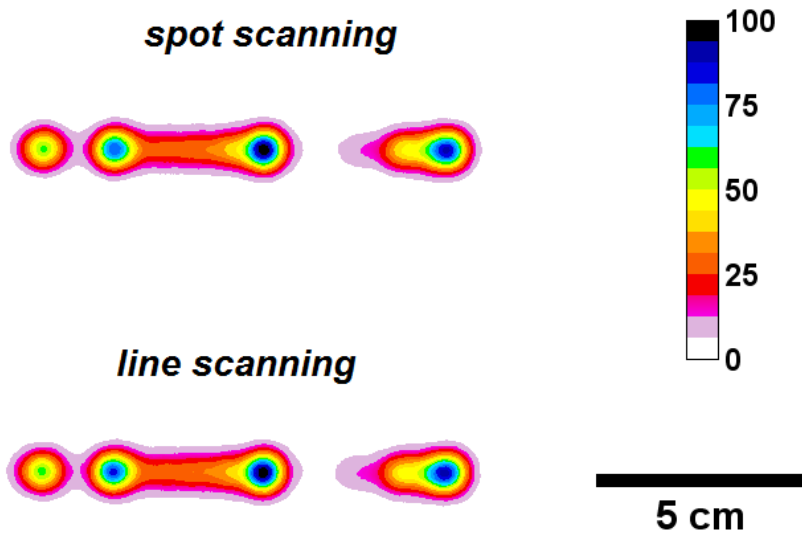
Line Scanning



c.f. 'Sliding-window'

Line (continuous) scanning

## Line/continuous scanning



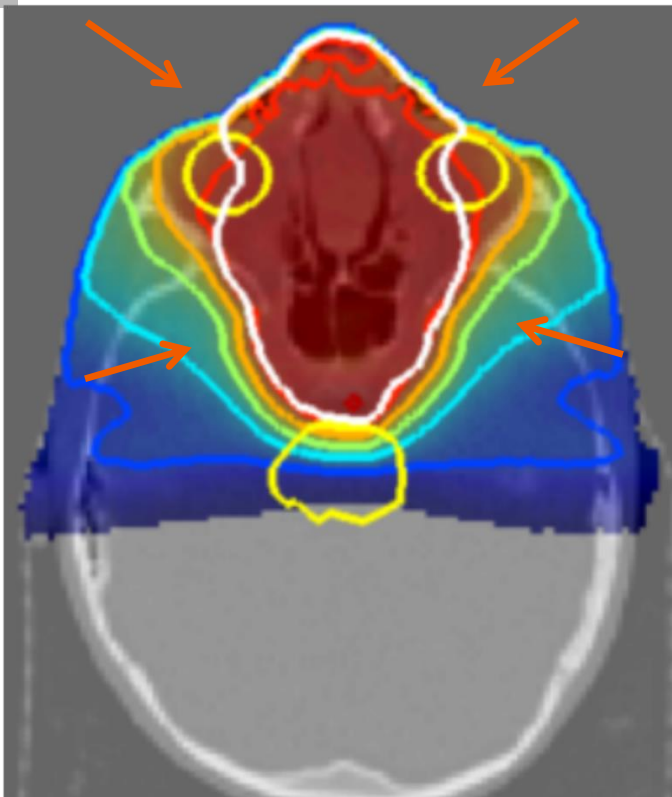
Treatment times for 0.6Gy delivered to a 300ml target volume

Spot scanning – 23s

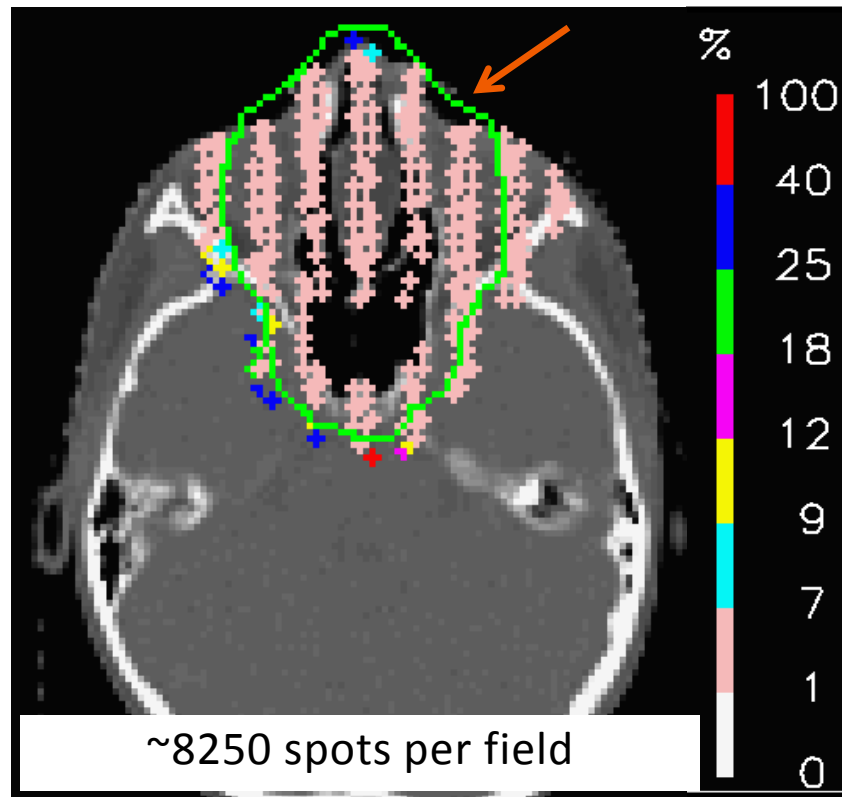
Line scanning – 10s

## Spot reduction

4 field IMPT plan



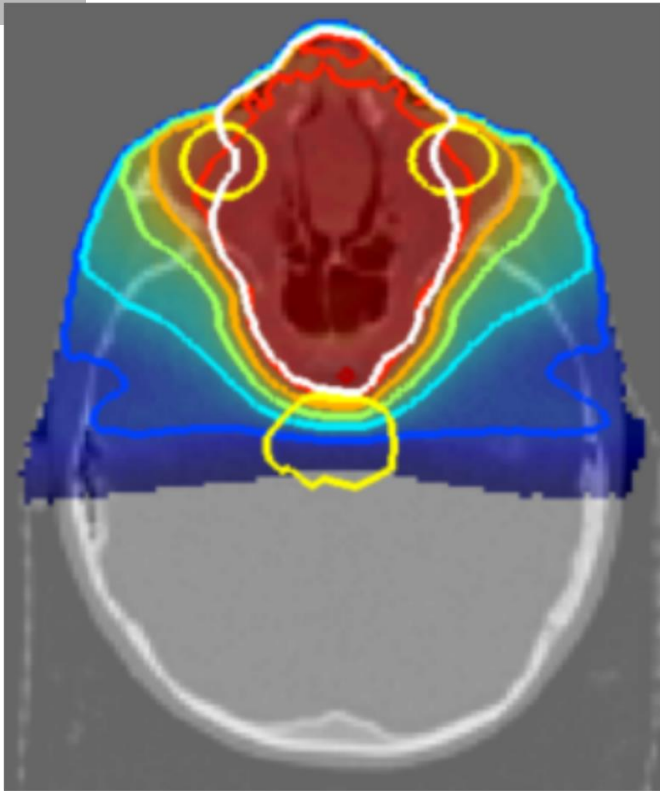
Bragg peaks (spots) for field 1



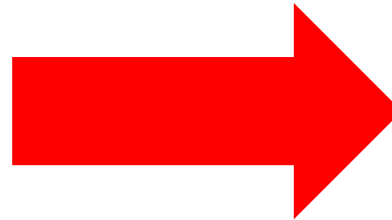
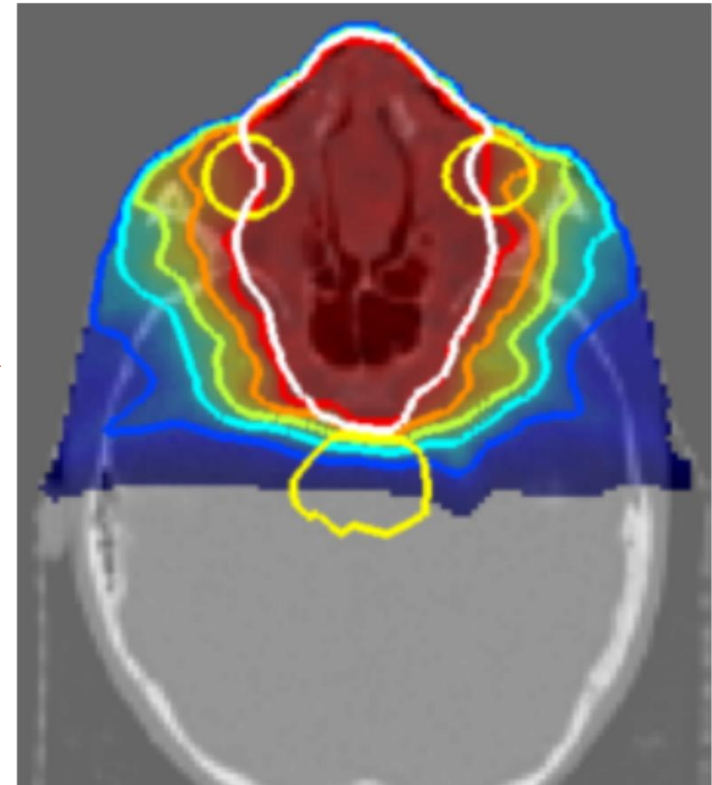
Do we need so many 'spots'?

## Spot reduction

Conventional PBS



Spot reduced



Spot reduction  
optimisation

Lomax et al, ESTRO 2003, Geneva

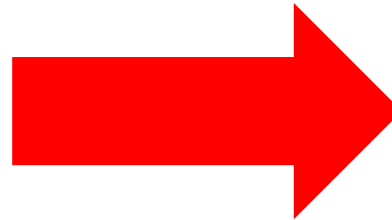
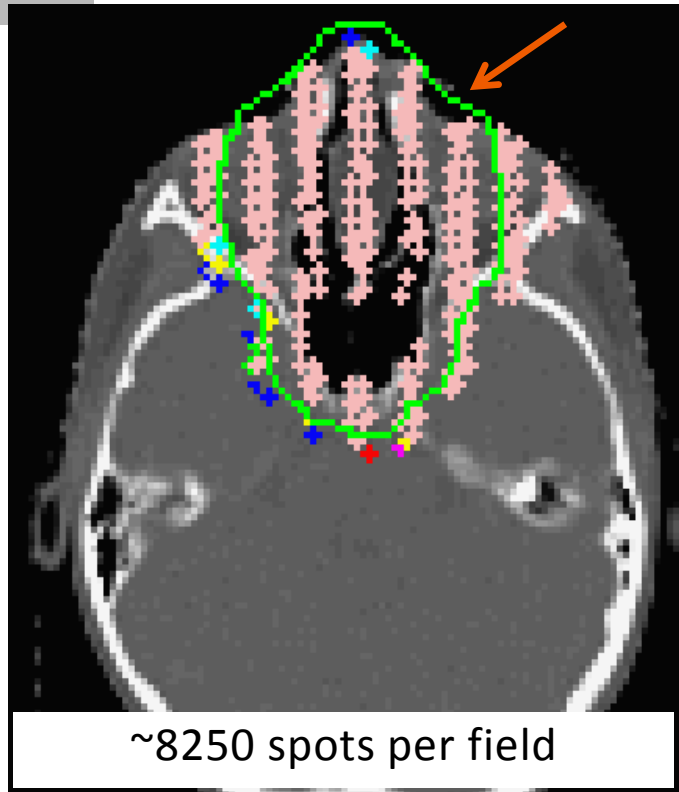
van de Water et al. Physics in Medicine & Biology 2013, 58

Belosi et al, PTCOG57, Cincinnati, 2018



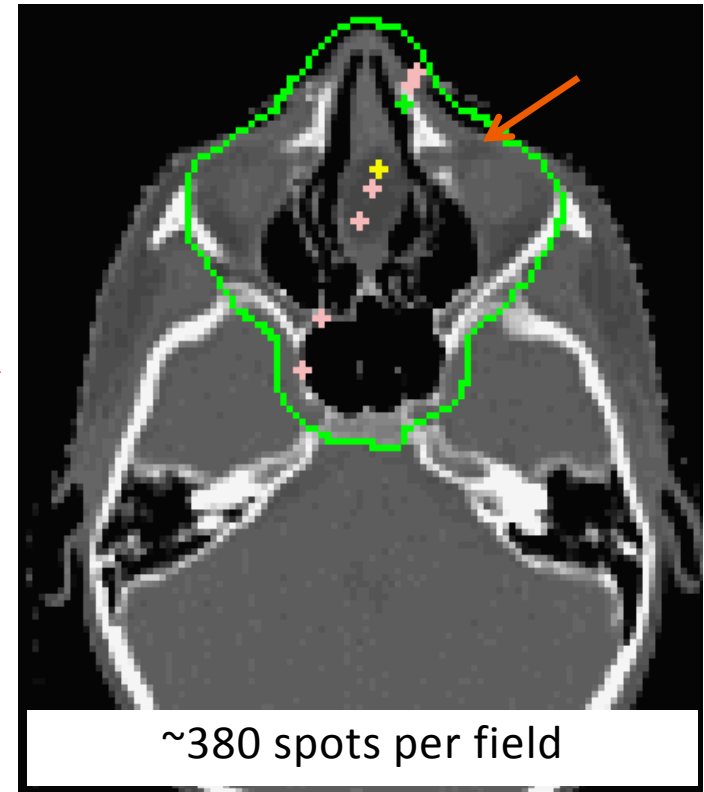
## Spot reduction

Conventional PBS



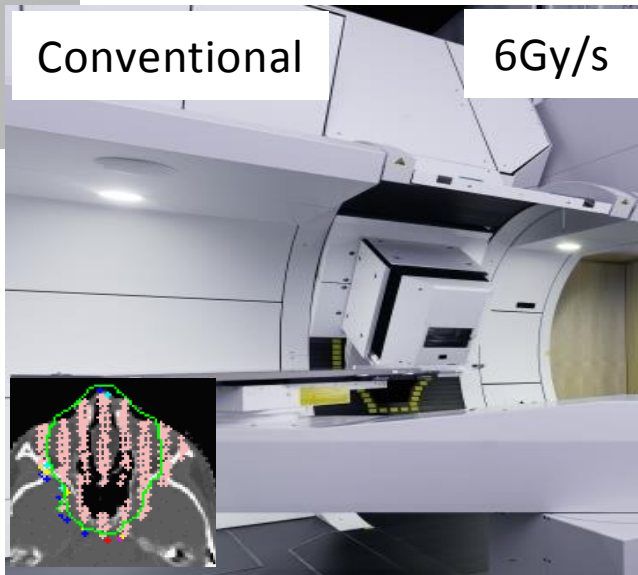
Spot reduction  
optimisation

Spot reduced



# Reducing delivery times

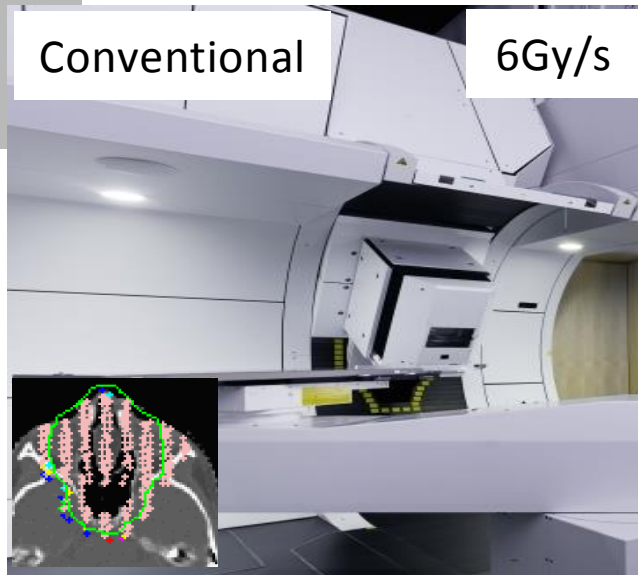
## Does this reduce treatment time?



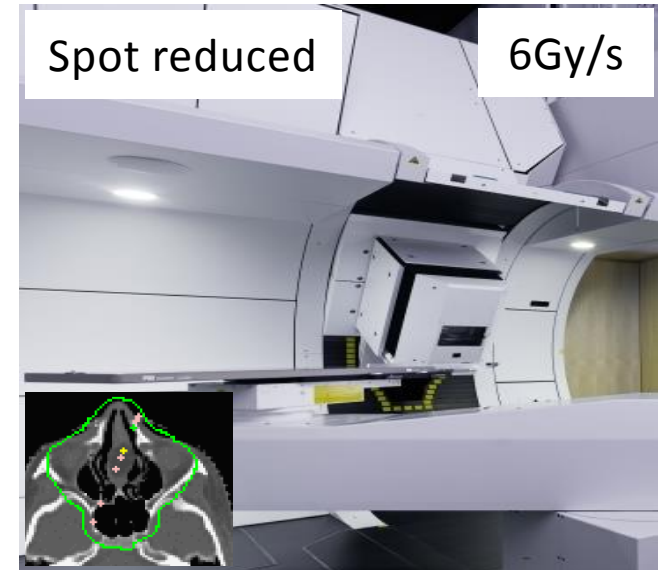
	Conventional plan
Spots/field	~8250
Delivery time/field (s)	~50

# Reducing delivery times

## Does this reduce treatment time?



Spot reduction



	Conventional plan	Spot reduced plan
Spots/field	~8250	~380
Delivery time/field (s)	~50	~28

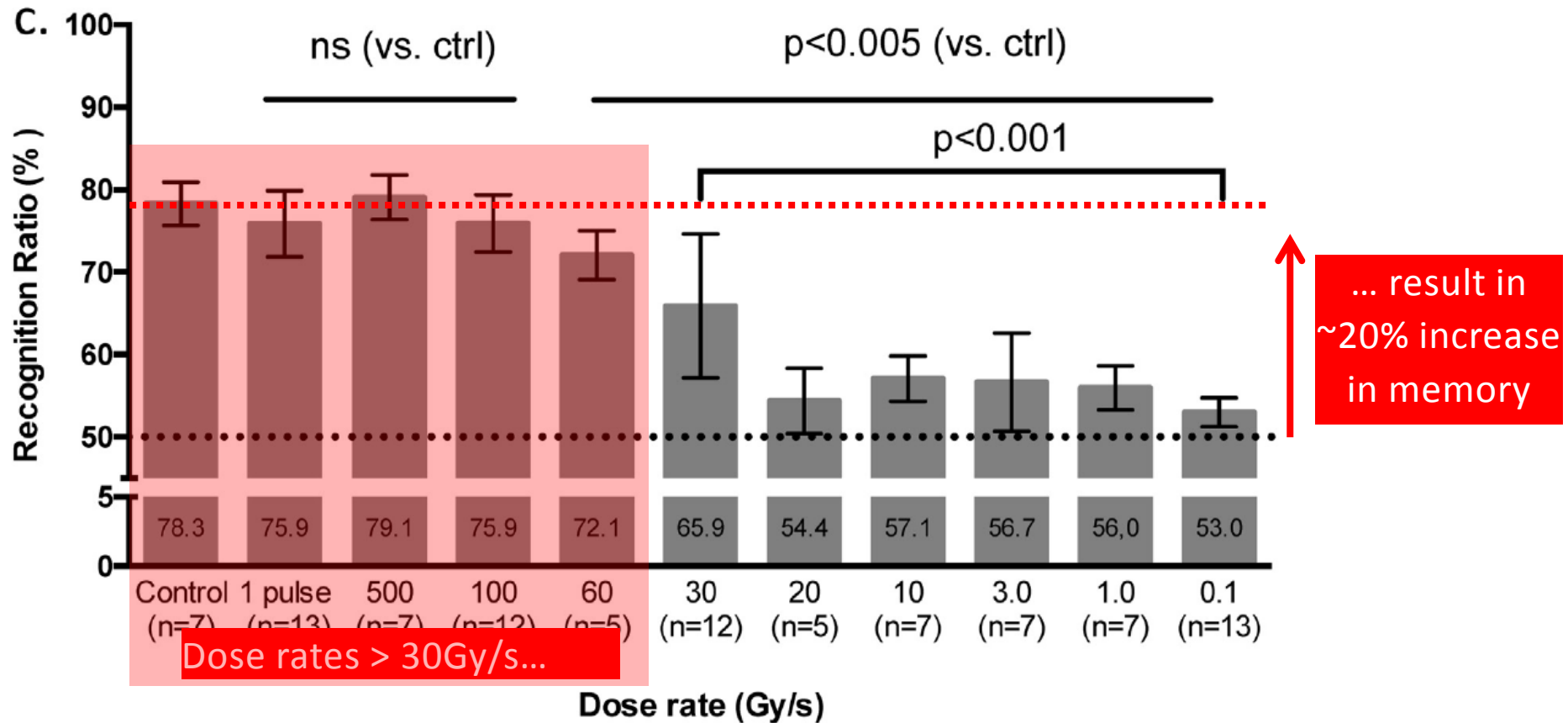
# Overview of presentation

1. Proton therapy and its delivery
2. Improving lateral penumbra
3. Reducing treatment times
4. Protons for FLASH?
5. Summary

# Protons for FLASH?

## The FLASH effect – Whole brain irradiation of mice

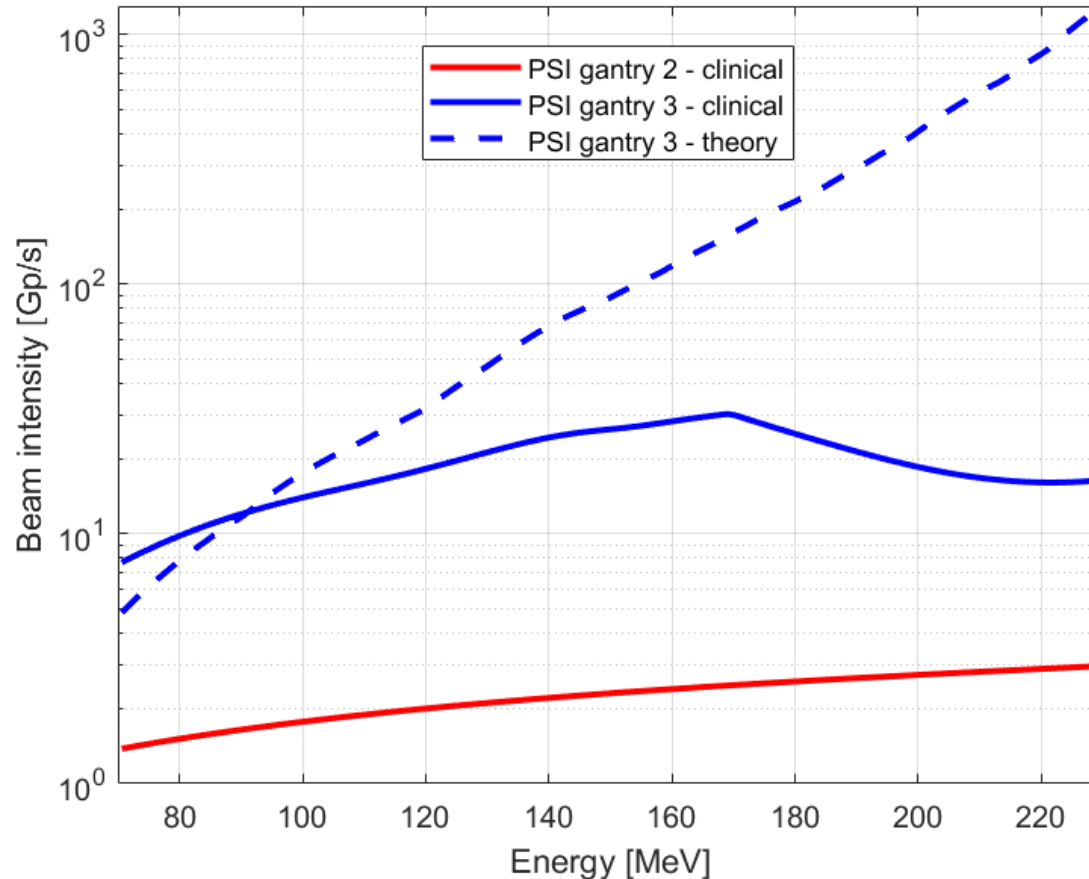
Irradiation: 10Gy @ 0.1 – 5MGy/s (4.5 MeV electrons)  
Endpoints: Memory preservation (Recognition ratio)



# Protons for FLASH?

## Proton dose rates

### Energy specific beam intensities at PSI



3300Gy/s!

Beam intensities without monitoring/regulatory limitations

60Gy/s

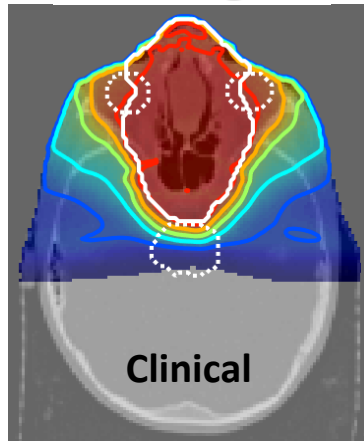
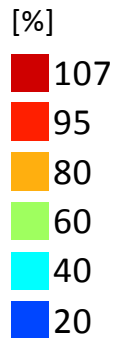
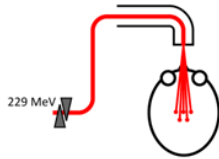
Limited by monitoring and regulatory issues!

6Gy/s

# Protons for FLASH?

PBS proton therapy for FLASH –  
How can we best exploit these intensities?

Upstream E-modulation



**Fields**

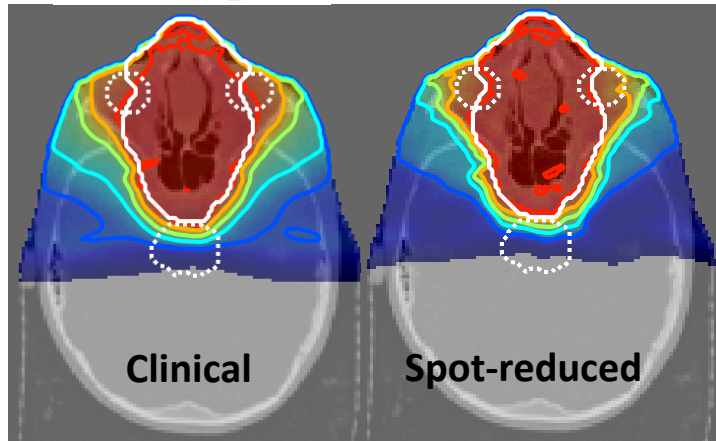
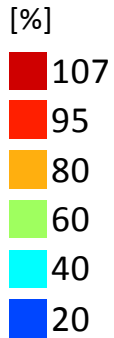
4

**Spots**

38635

# Protons for FLASH?

PBS proton therapy for FLASH –  
How can we best exploit these intensities?

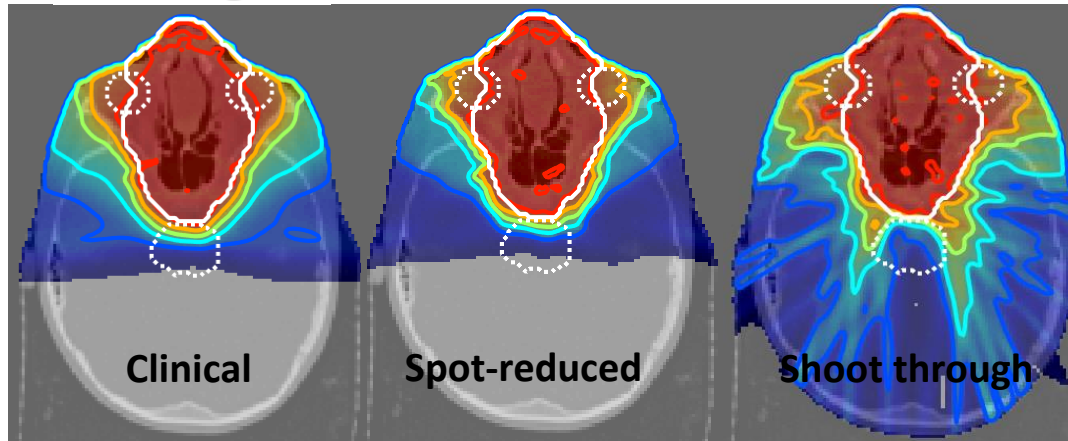
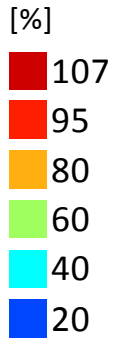
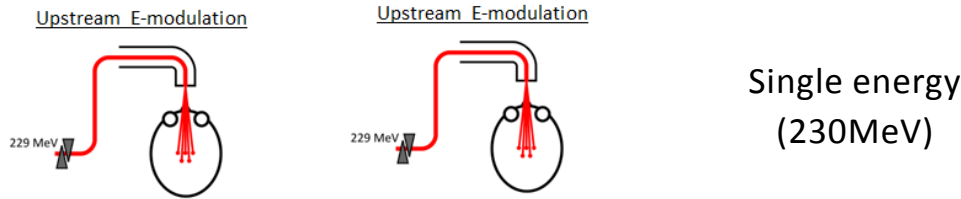


<b>Fields</b>	4	4
<b>Spots</b>	38635	854



# Protons for FLASH?

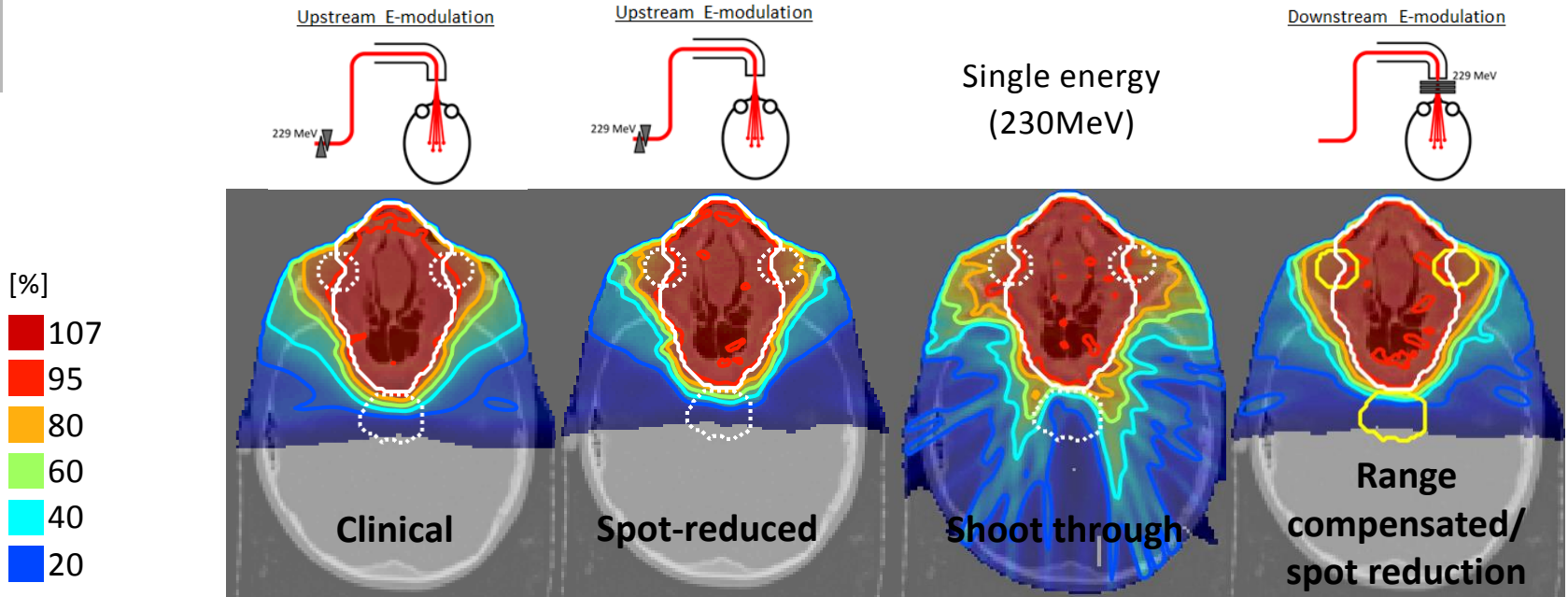
PBS proton therapy for FLASH –  
How can we best exploit these intensities?



<b>Fields</b>	4	4	116
<b>Spots</b>	38635	854	2185

# Protons for FLASH?

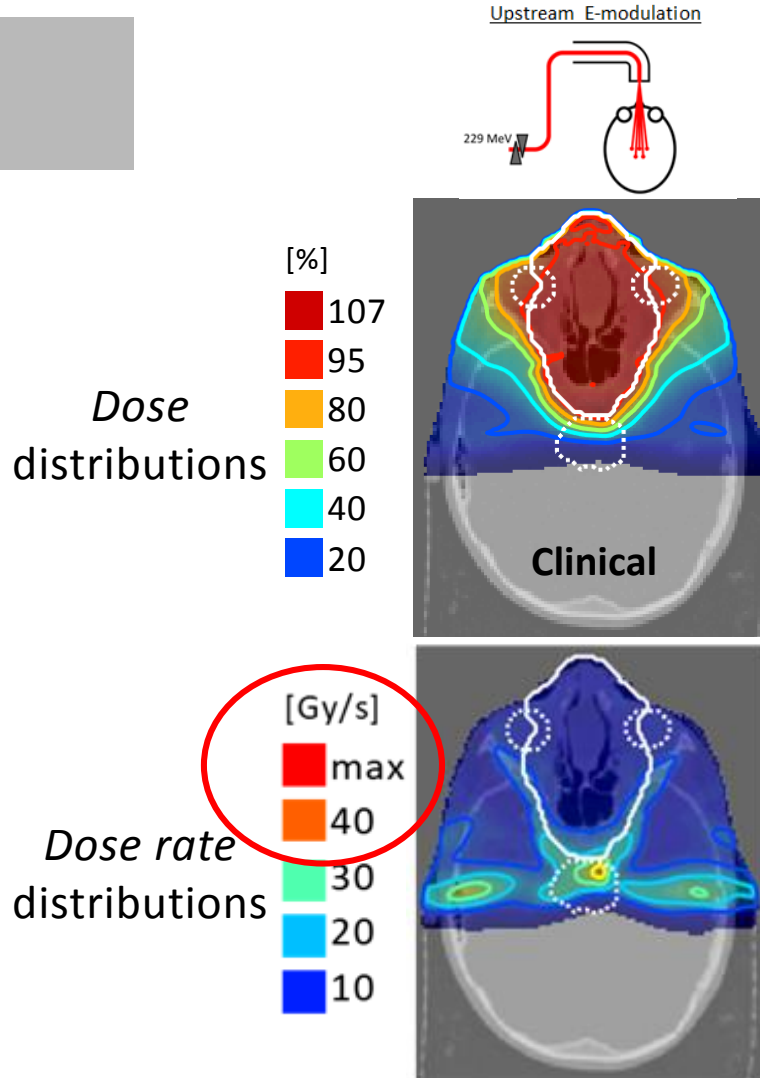
## PBS proton therapy for FLASH – How can we best exploit these intensities?



<b>Fields</b>	4	4	116	4
<b>Spots</b>	38635	854	2185	535

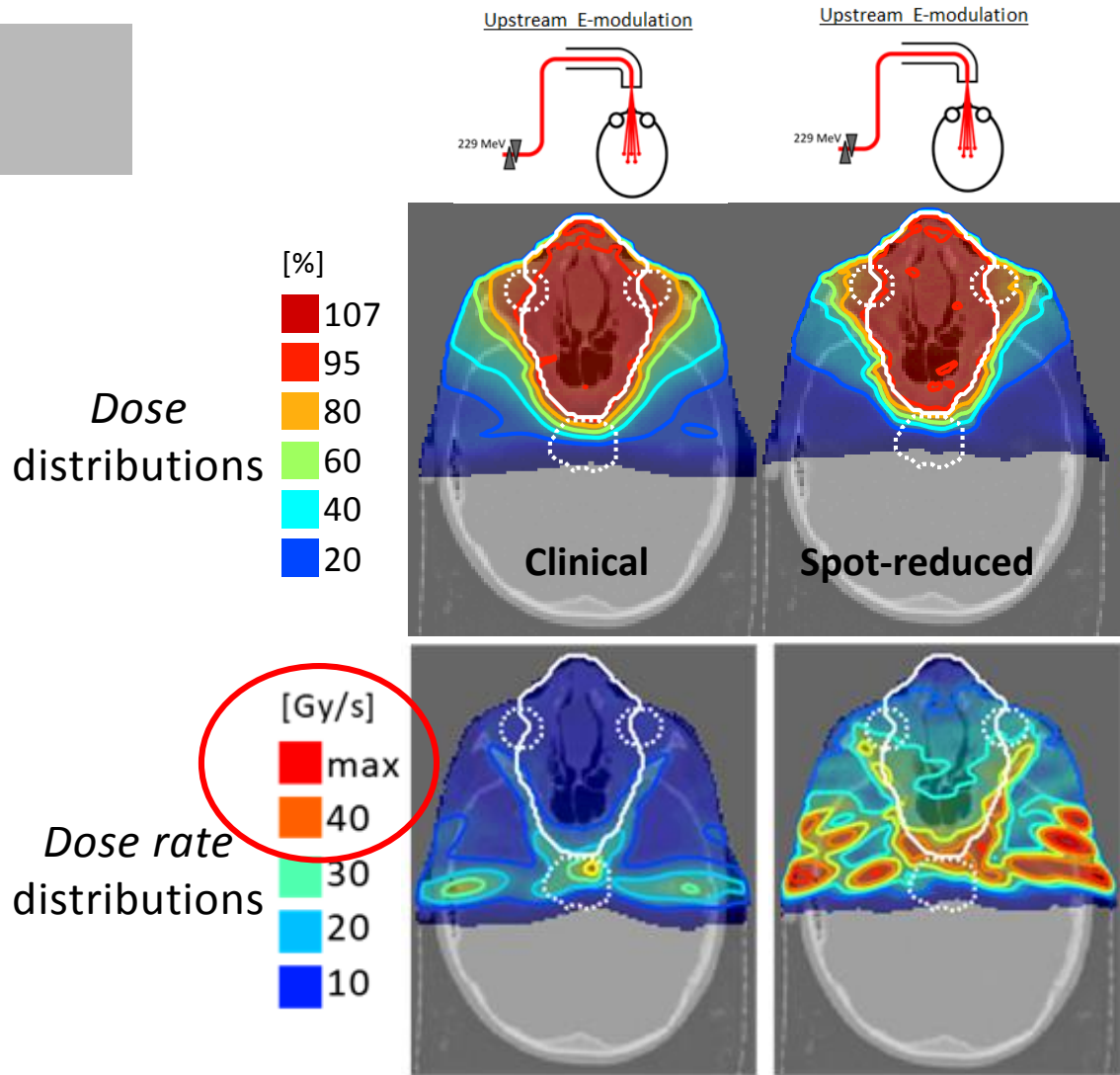
# Protons for FLASH?

## Estimated dose rates for 6Gy fraction



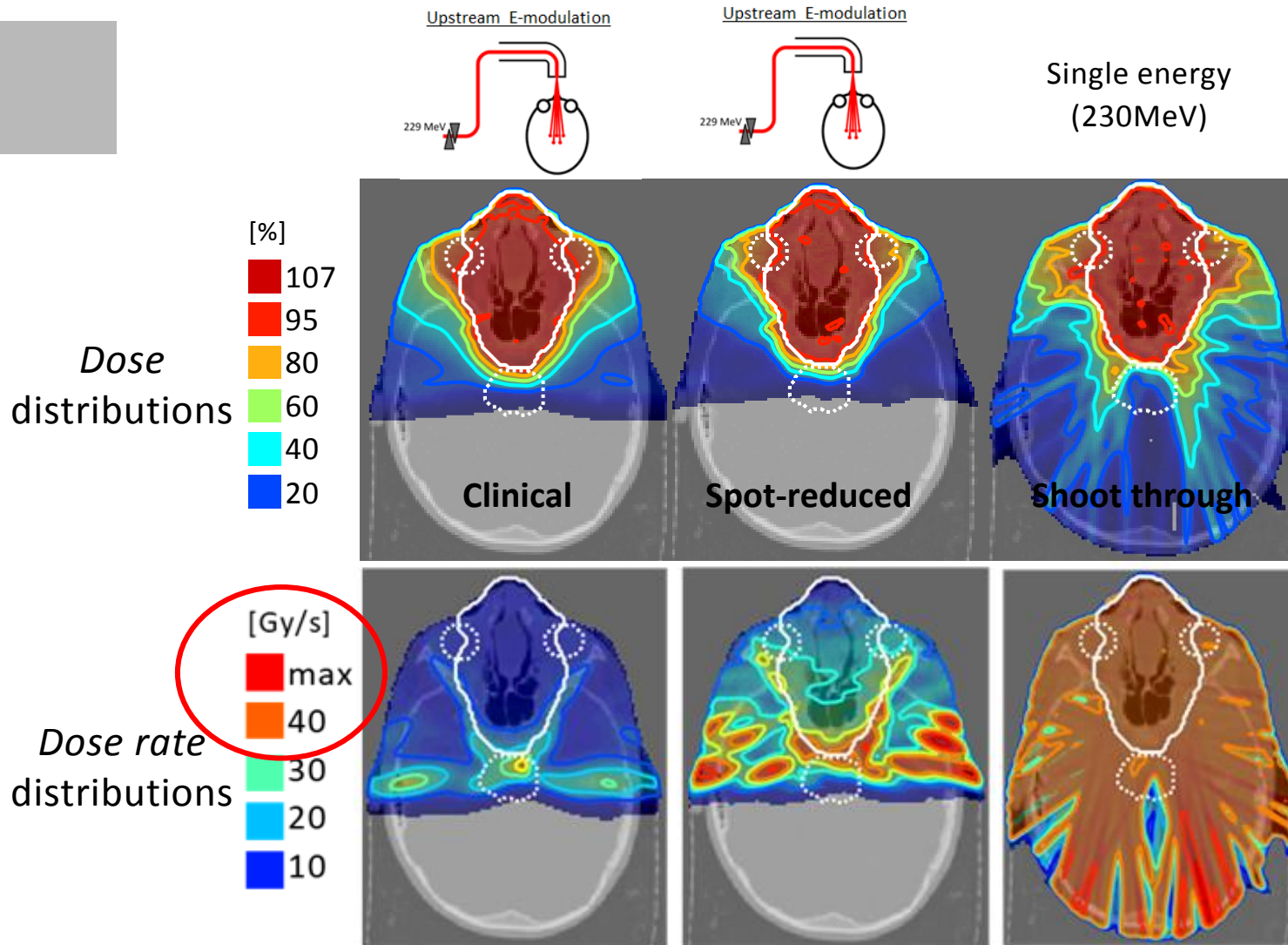
# Protons for FLASH?

## Estimated dose rates for 6Gy fraction



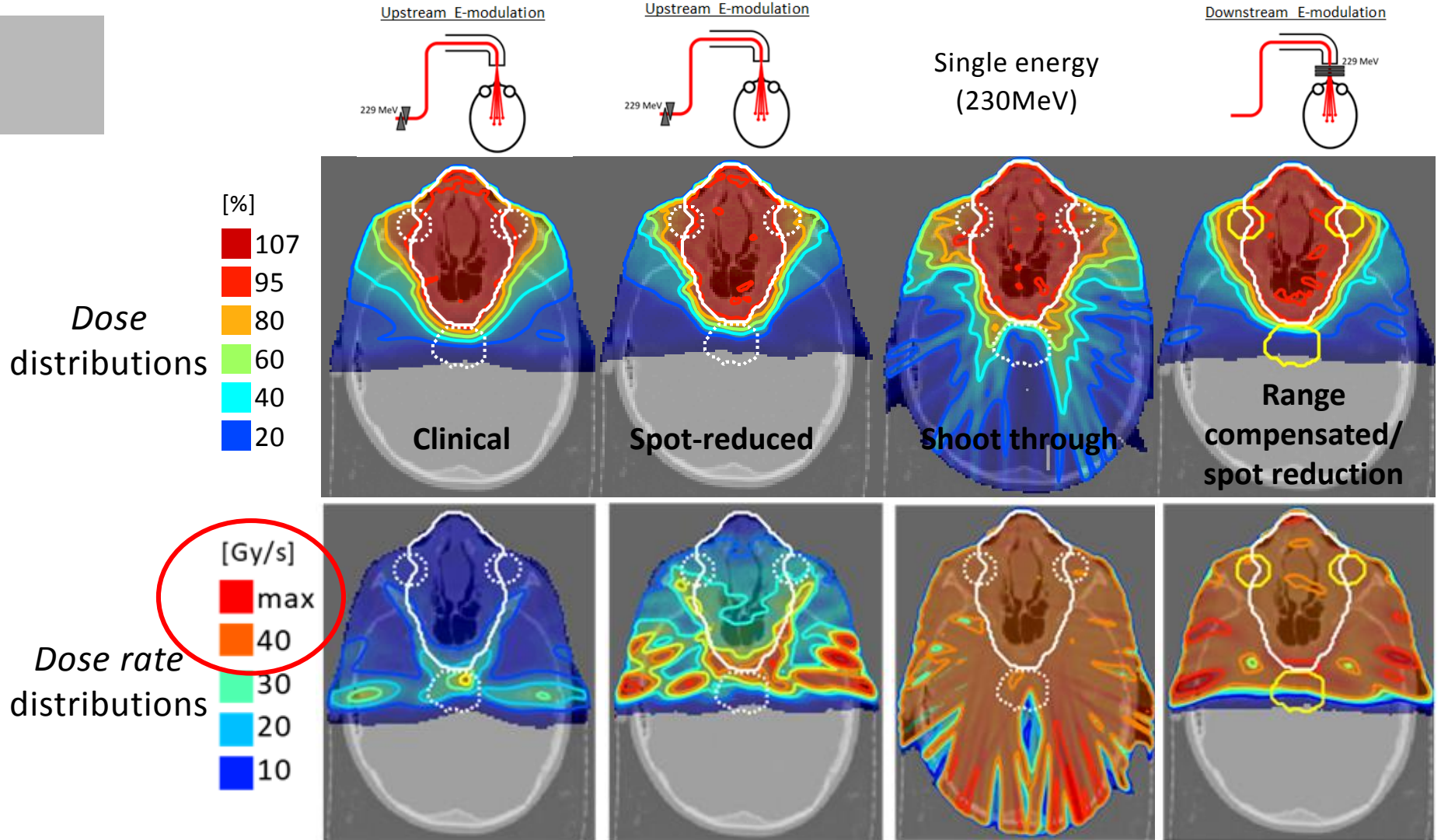
# Protons for FLASH?

## Estimated dose rates for 6Gy fraction



# Protons for FLASH?

## Estimated dose rates for 6Gy fraction



# Summary

- The 3D localization of the Bragg peak allows for high degrees of modulation, leading to exquisite levels of dose conformation
- PBS is currently the most flexible and (now) most widely used delivery modality
- But improvements are still necessary...
  - Reducing treatment times
  - Improving lateral penumbra
  - FLASH compatible PBS
  - ...
- **Whatever, there are still lots of interesting developments to be done in accelerators, beam delivery, medical physics, biology and clinics...**



Thanks for your attention.