pCT meeting, April 25 2013

Clinical interests and expectations of proton imaging

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Plan

I. Introduction on :
- Proton imaging
- Proton therapy

II. Clinical interests of p+ imaging :
- In diagnostic
- In therapy

III. Conclusions

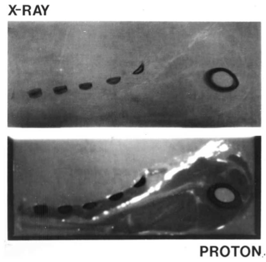
Introduction

- 1963 : Allan Cormack pointed out the possibility of using heavy charged particle for a CT

  Initially ➔ diagnostic aims !

- 1968 : 1° p+ radiography by *Koehler et al*. (lamb chop)
- 1972 : 1° CT reconstruction α-CT (with α particles)
- 1976 : 1° pCT prototype

Progress in X-Rays techniques ↗ +++ ⬄ Studies using p+ for imaging ↘



Koehler et al. (Harvard)

Nevertheless ➔ Expansion of proton radiation therapy centers
➔ Applications for proton therapy = very interesting
➔ Improve treatment accuracy

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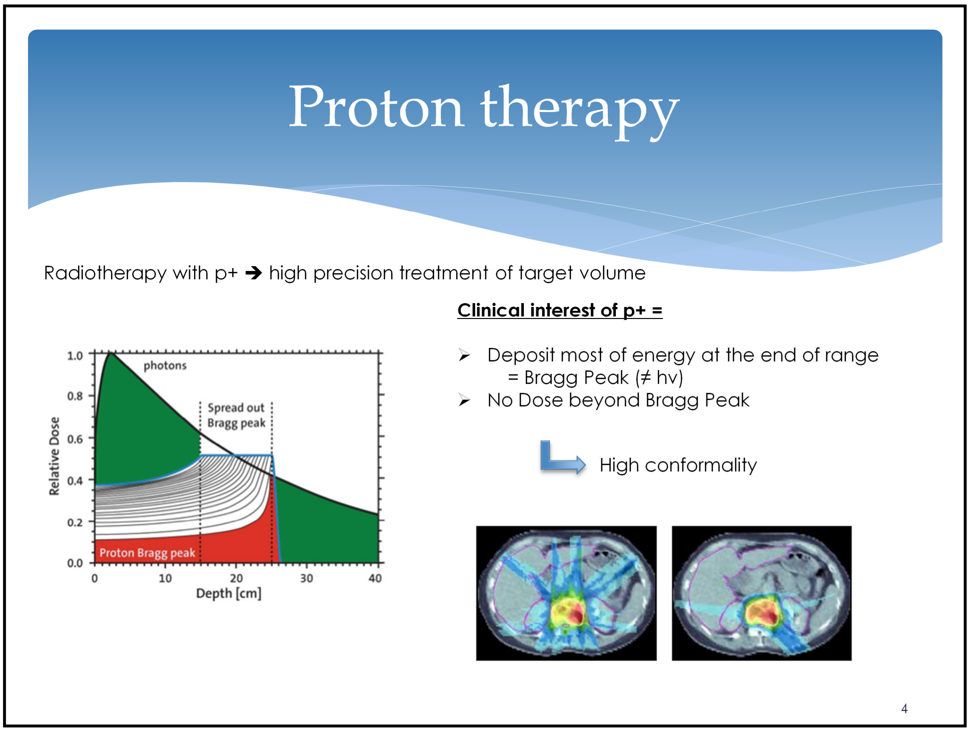
Historical backgrounf of p+ imaging

In 1963 …
It is important to say that, at this time, …

But due to the fast progress in X-Rays techniques

Nevertheless, today, because of …

Because it would improve ttt accuracy



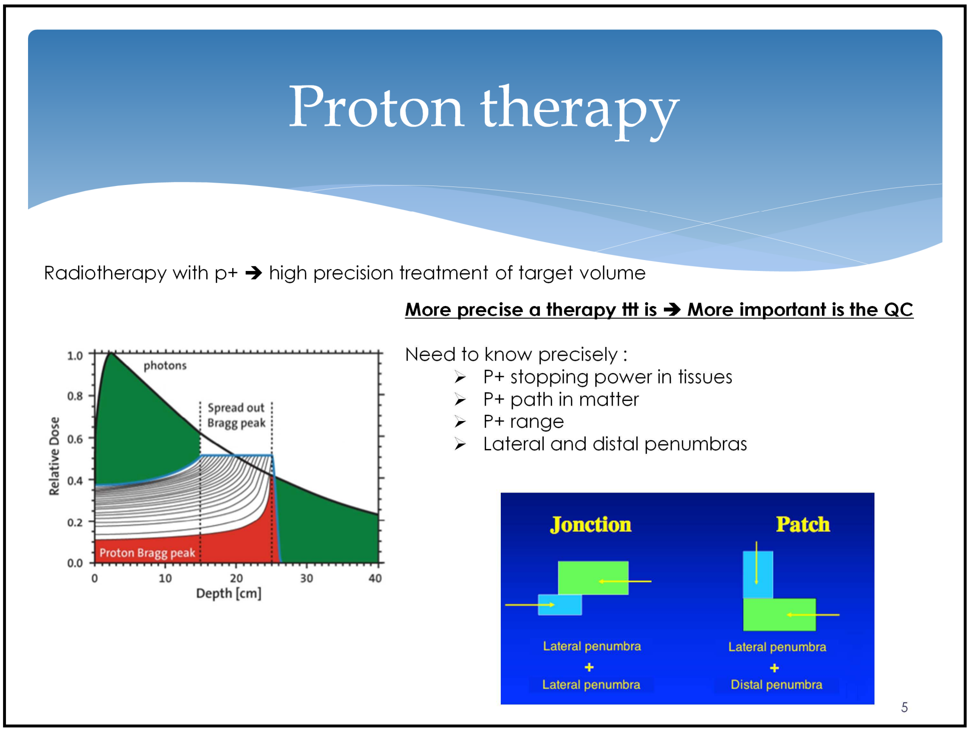
Effectively

The major interest of using p+ is that It deposit the most of his energy at the end of his range ➔ it is the so called Bragg Peak

Accordingly, there is No Dose after Bragg Peak, and it allows to sparing tissues beyond BP

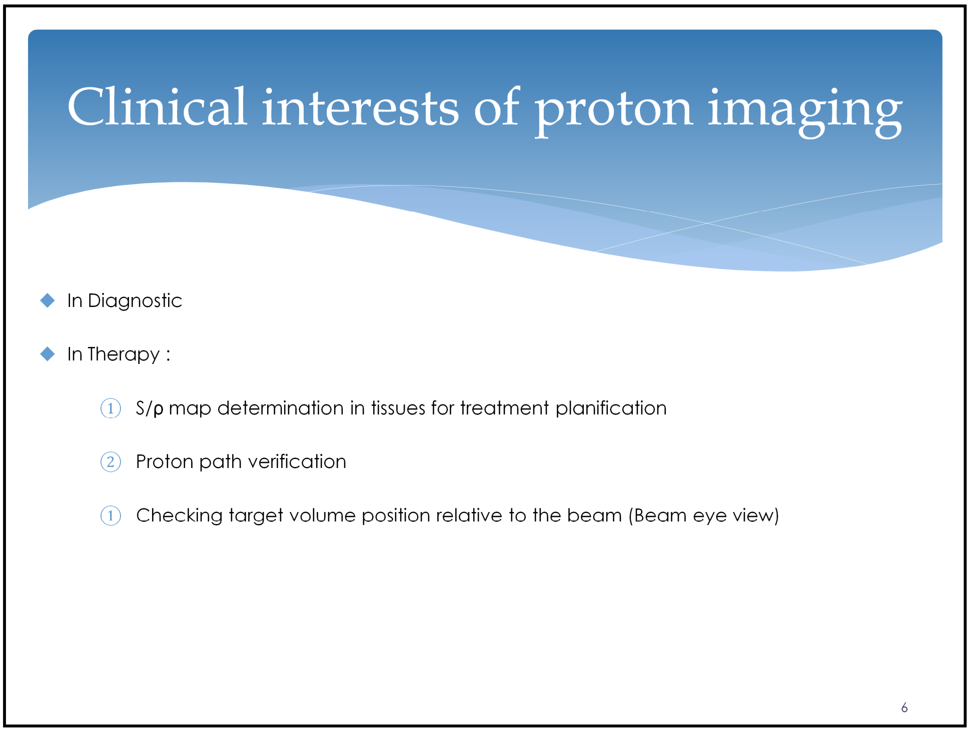
With the poor lateral penumbra, **it is also possible** to spare tissues lateral to the beam

These characteristics of p+ lead to a High Conformality ttt



But the key issue is « the more precise a ttt is, the more important is the QC »

And we need to know precisely

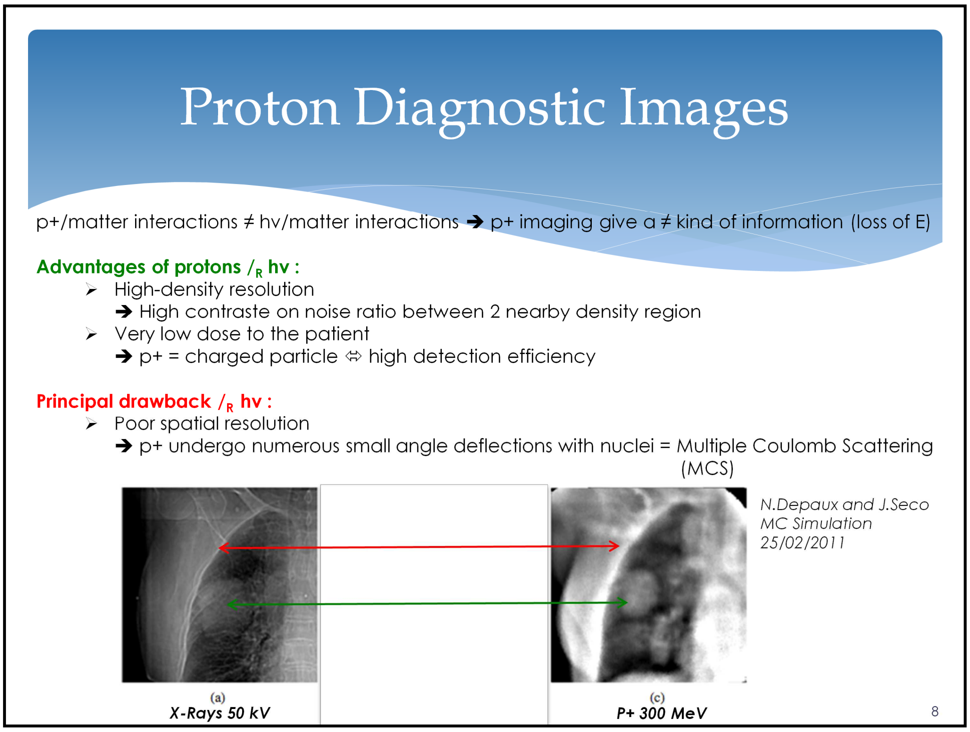


Now, we well focus on the clinical interests of p+ imaging

Firslty in diagnostic

And secondly in therapy

Diagnostic



Protons/matter and photons/matter interactions **are quite differents**

And thus proton imaging **give us** a different kind of information : a loss of E in matter of protons

The advantages of p+ **relative to** photons are :

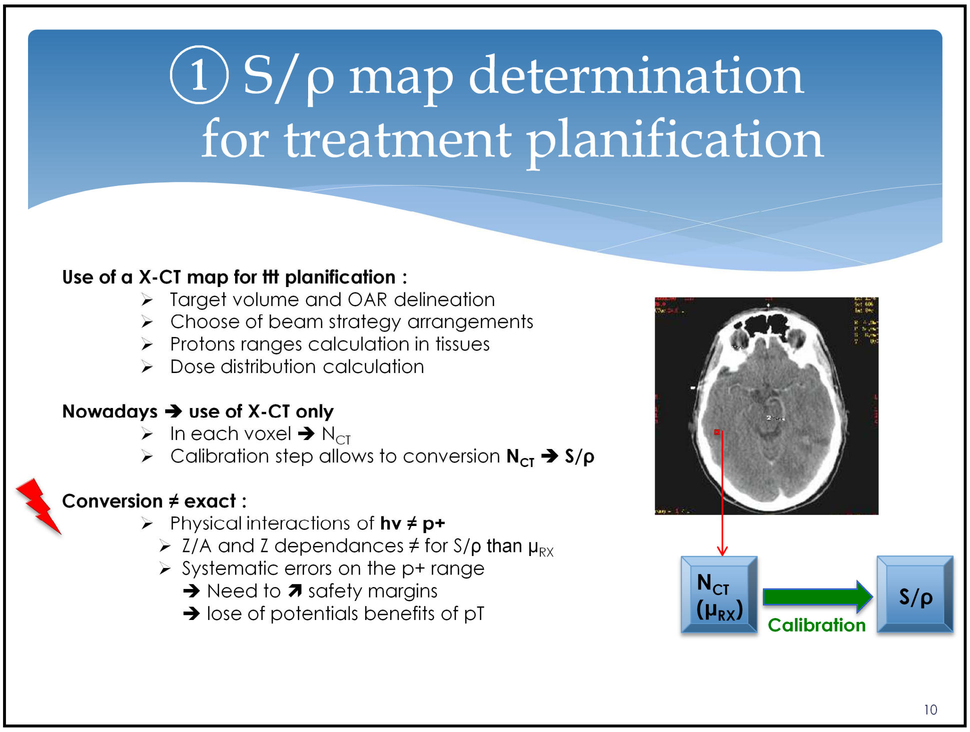
His high density resolution

As we can see on this proton radiography, there is a high contraste on noise ratio between 2 nearby density region

The second advantage is the very low dose to the patient, **because of the high detection efficiency of** a charged particle

The principal drawbacks **relative** to photons is the poor spatial resolution **due to** numerous small angle deflections with nuclei (or multiple Coulomb Scattering)

And now, we will see the clinical interests and expectations for therapy



The first interest would be the Stopping power map determination for ttt planification

Todays, we use a X-CT map for 1) 2) 3) 4)

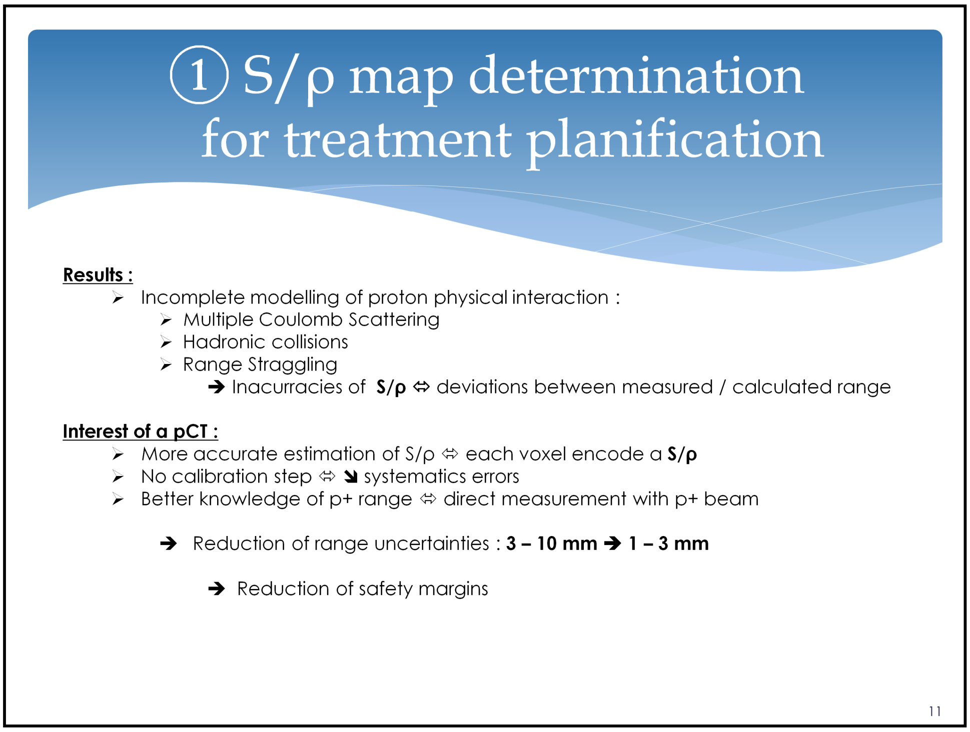
But, because we use a X-CT, in each voxel we measure a CT number N_{CT} and we need a calibration step to conversion of $N_{CT\ toward}$ protons Stopping Powers

The issue is that the conversion isn't exact

the physical interactions of photons are **quite different** for protons

and it leads to systematic errors …

In conclusion, we need to … and we lose a …



Because of this calibration step, there is an incomplete modelling of proton physical interaction with matter :

an incomplete modelling of …

id …

id …

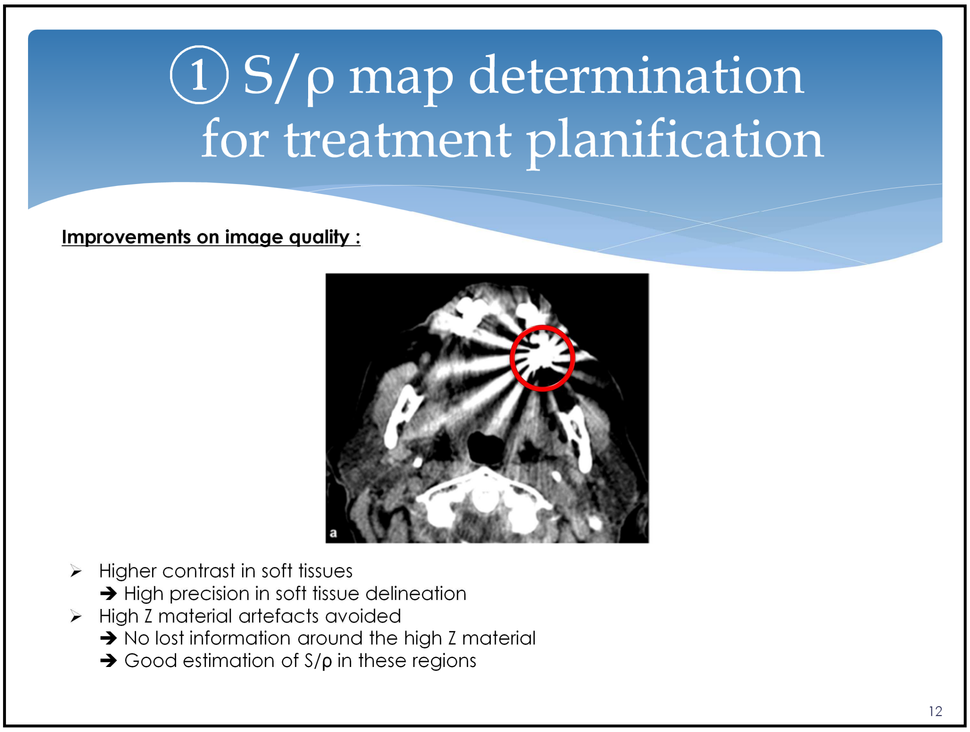
and inacurracies in S/ro estimation

therefore, this incomplete modelling leads to significant deviations …

The interest of a pCT is that it could give a more accurate estimation of S/ro

We expect a reduction of range uncertainties from 3 to 10 mm to 3 to 1 mm

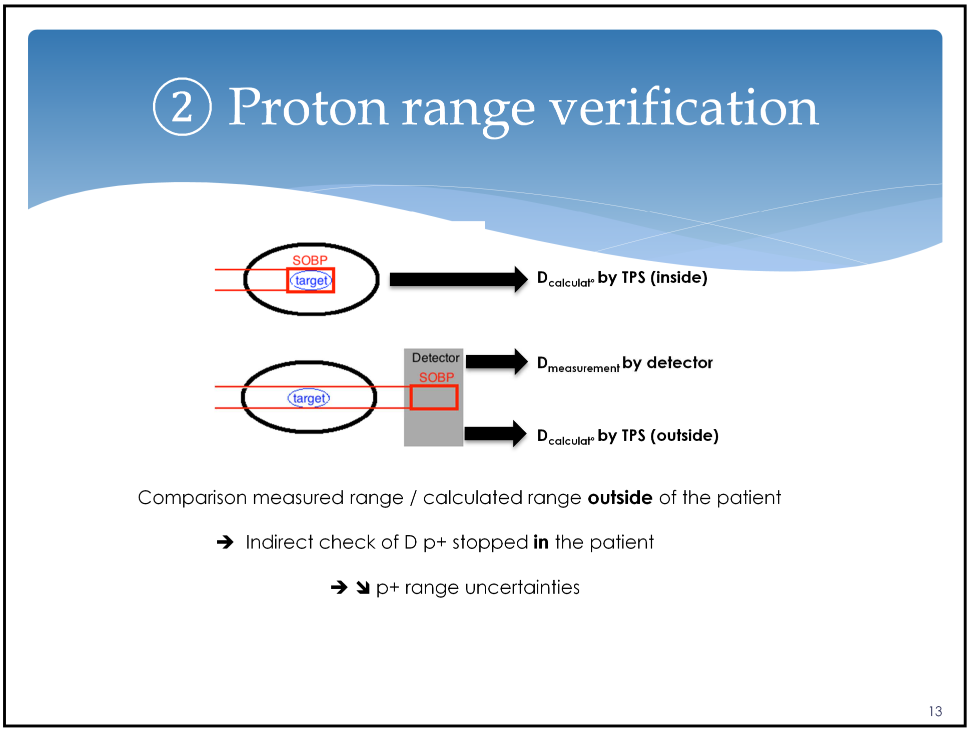
and therefore a reduction of safety margins



An other benefit for ttt planification is the improvement of image quality

The Higher constrast in soft tissue **offers** a high precision in soft tissue delineation

And the high Z material artefacts are avoided, and therefore there is no lost information around this type of materials

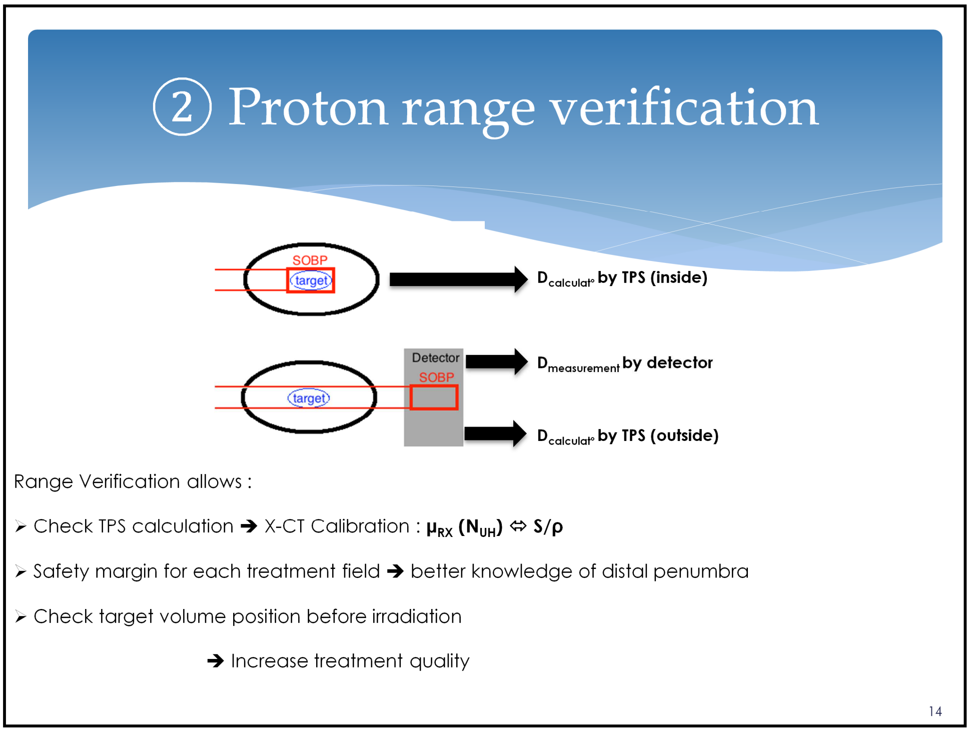


The second potential benefit of proton imaging is the proton range verification

If we check that the measured range and calculated range outside of the patient are **accordingly**

It would provide an indirect verification of dose deposited by stopped p+ in the patient

It leads to a decrease of p+ range uncertainties



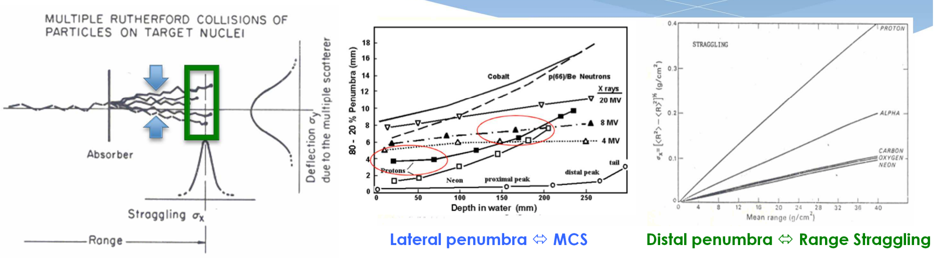
In fact, the range verification allows

a check of TPS calculation, meaning the X-CT calibration

a precise measurement of safety margins for each ttt field

a check of target volume position before irradiation

③ New beams arrangements



Lateral penumbra ⇔ MCS

Distal penumbra ⇔ Range Straggling

With p+ ➔ Sparing OAR with lateral penumbra
➔ At intermediate depth ⇔ pen_{lat} = **Not better than hv**

If sparing OAR with distal penumbra
➔ $pen_{dist} < pen_{lat}$ ➔ **Real benefit especially for p+**

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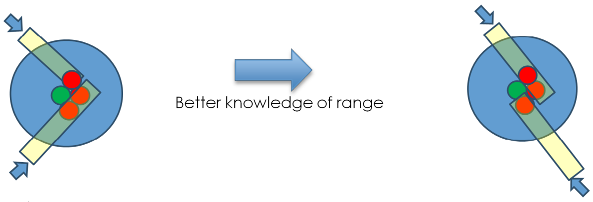
These distal protection would be impossible for ions because of the fragments beyond Bragg Peak

③ New beams arrangements

	OAR sparing		
	Apparent best choice	The safest	Reasons
Protons	Distal range	**lateral penumbra**	Range uncertainties
Heavy ions	Distal range	**lateral penumbra**	Range uncertainties and fragments

If precise knowledge of beam range ➔ offer option of distal range sparing of OAR
➔ **↗ clinical interests of p+ $/_R$ ions**

Impossible for heavy ions ➔ **fragmentation tail !!!**



Sparing with lateral penumbras

Sparing with distal one

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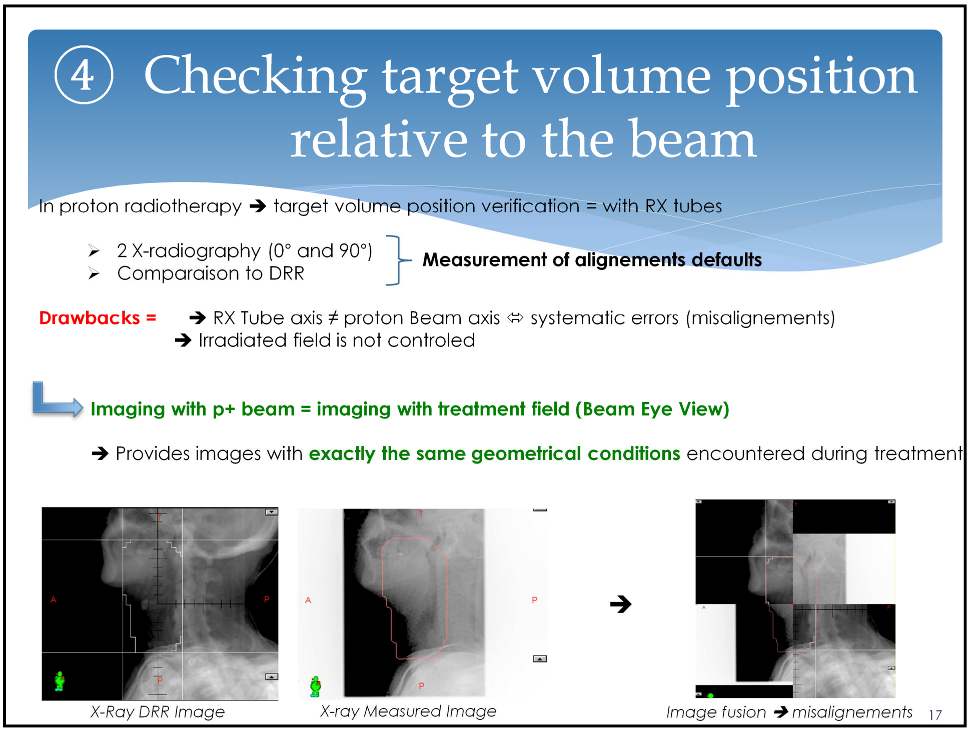
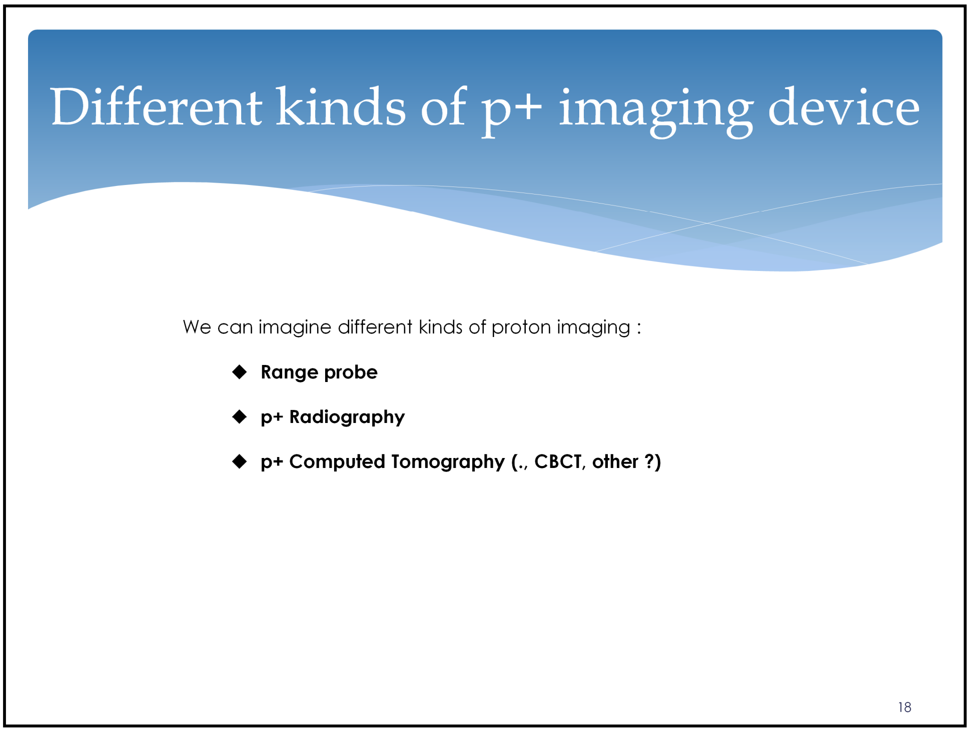
Difficultés faire un Arc avec un bras isocentrique p+



Difficultés faire un Arc avec un bras isocentrique p+

Même algo pour calculr d ttt que pour calculer im drr



The more interesting system and the more easiest is the pCT or pCBCT ?

Wath kind of proton computed tomography : classical one, CBCT, or an other system ?
Knowing existing facilities

Proton Computed Tomography

pCT specifications for pT :

	Parameter	Expected value
Source	Energy	> 250 MeV ➔ BP outside of the patient
Accuracy	R_S R_ρ	**< 1 mm ➔ No** **< 1 % ➔ OK**
Time efficiency	Data acquisition Reconstruction	**< 5 min** **< 15 min** } ➔ **difficult**
Dose	D_{max} scan	**< 5 cGy ➔ OK**

➔ **The imaging device should be consider the limitations of the pT facilities :**

Rotation speed of gantry
Forbidden angles of the gantry
Beam maximum energy
Adapted for active scattering / passive scattering
Detectors intrinsic limitations
etc ...

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We have to consider the « actuelle » limitations of p+ imaging

Adapted for passive scattering as for active scattering

Has to be

Conclusion

Radiotherapy with p+ = increasing ttt technique

- High precision treatment ➔ Need to know precisely p+ path in matter

Negative points =

- No image guidance with ttt beam available
- No direct measurement of S/ρ patient map ⇔ N_{CT} ➔ S/ρ calibration step
  - It leads to systematic errors in p+ range estimation

Limiting factor for a p+ imaging device in routine = **lack of R_S** induced by MCS

- **Image guidance in pT ➔ why not ?**
  ➔ Image quality of the DRR could be adapted to RG_{p+}
- **In pCT for ttt planning ➔ impossible**
  ➔ We need a $R_S \approx 1$ mm

Conclusion

However :

- Imaging devices proposed :
  - Expensive detectors (hodoscope + range telescope)
  - List data mode ➔ long reconstruction time
- Gantry pCT ➔ long rotation time

Imaging devices for pCT proposed
➔ not yet realistic in clinical routine

➔ Need to develop systems user friendly in clinical routine

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Thank you for your attention