



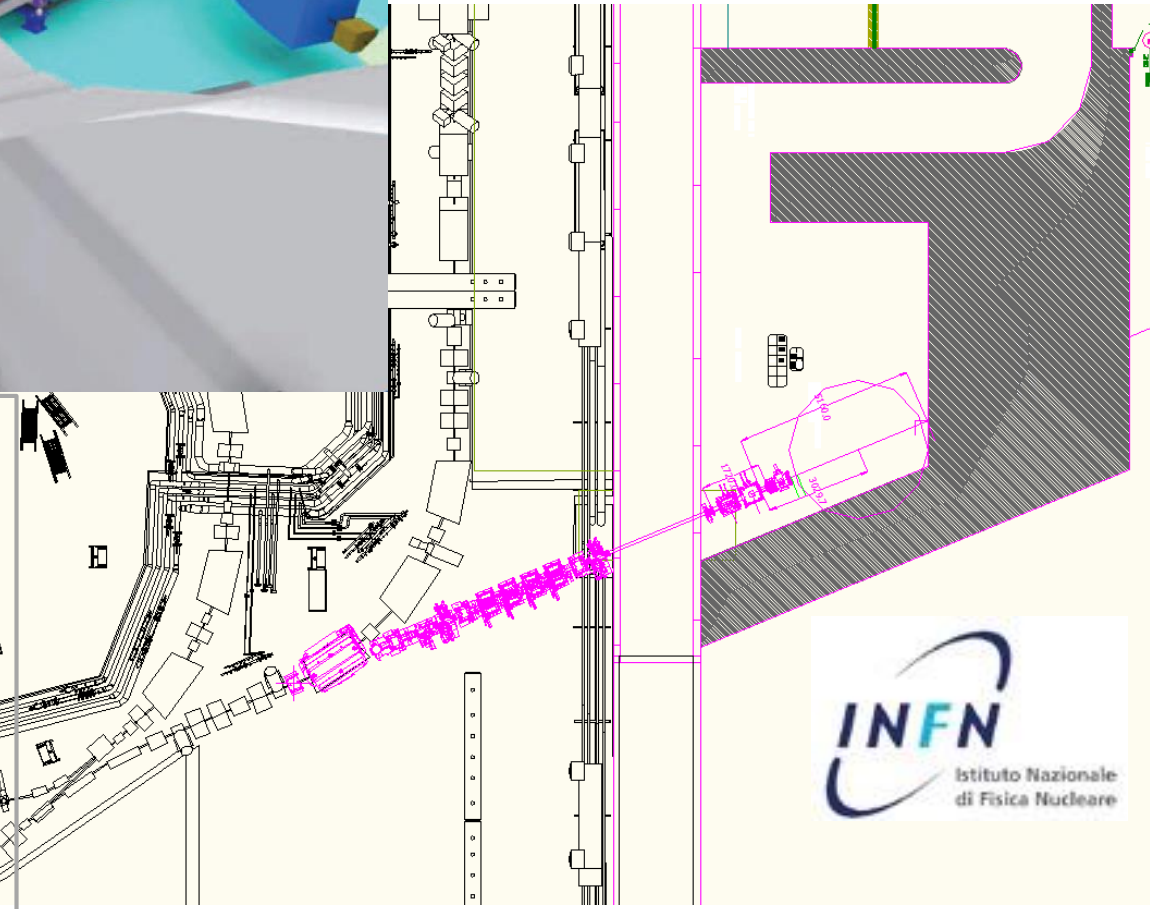
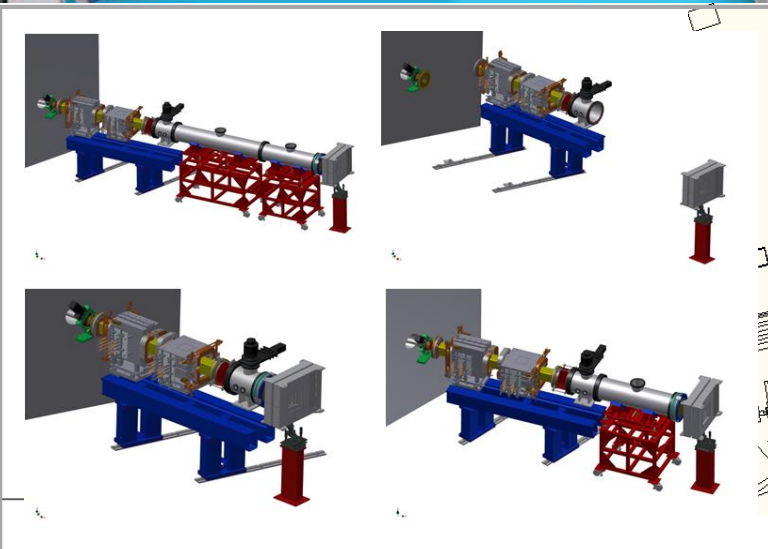
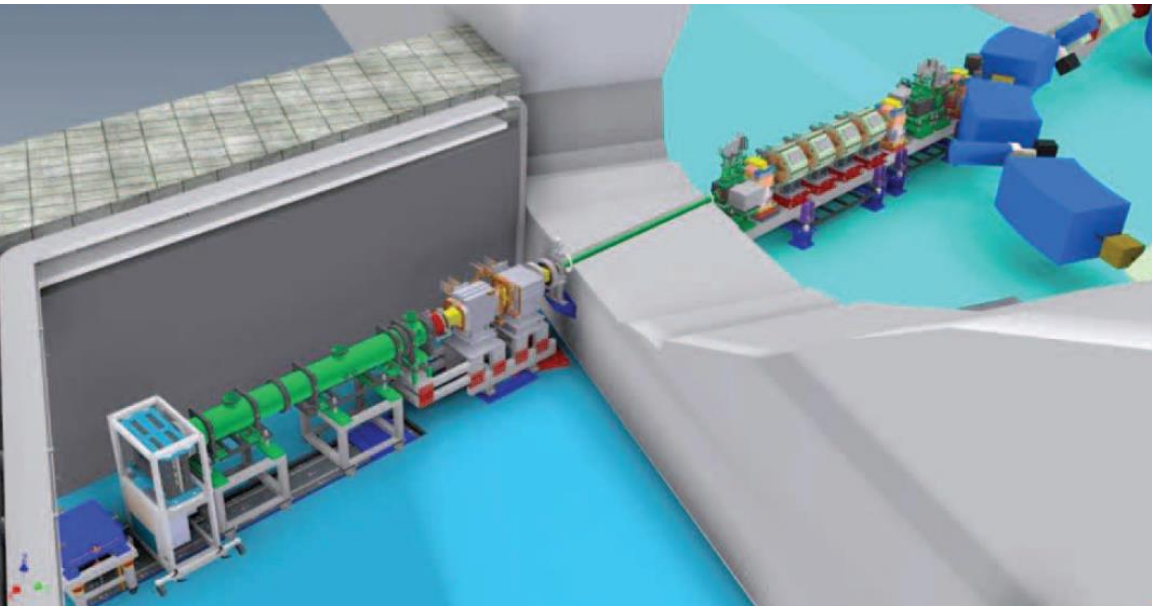
Concepts and ideas for a new synchrotron design

M. Pullia

Ions for cancer therapy, Archamps, June 19th -21st 2018

Some activities at CNAO

Experimental room

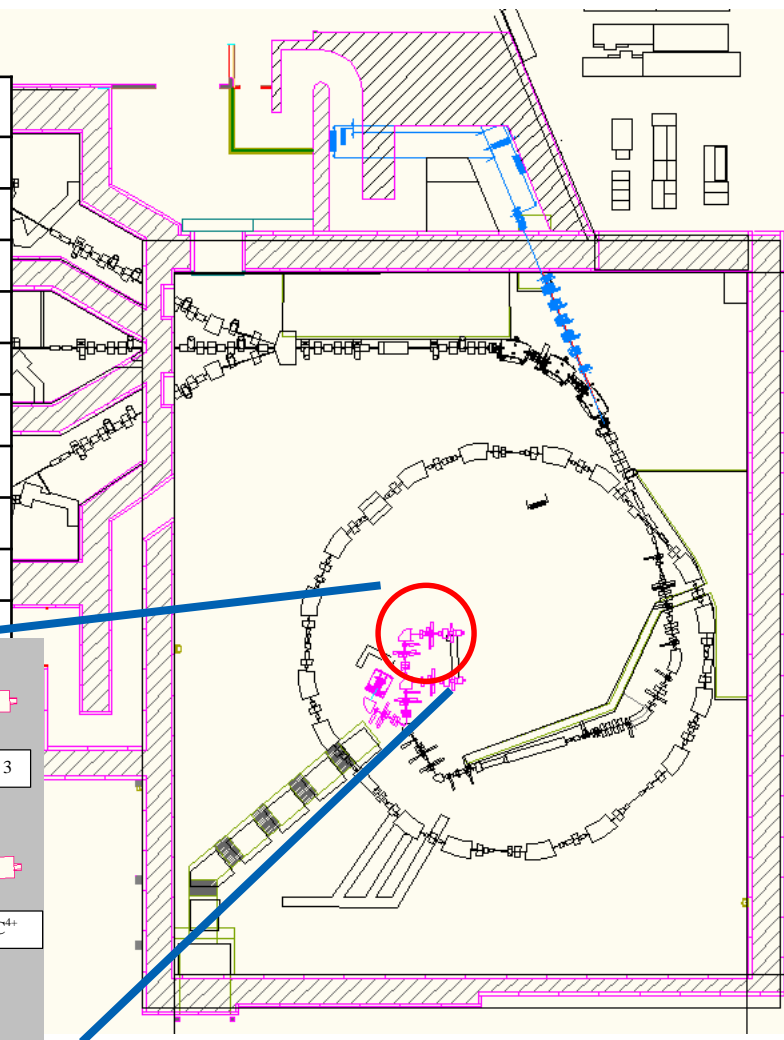
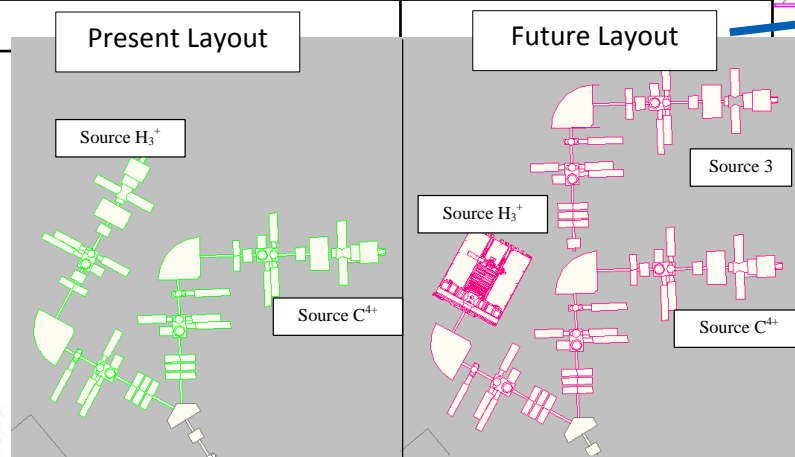


Experimental room – phase 2 – 3rd source

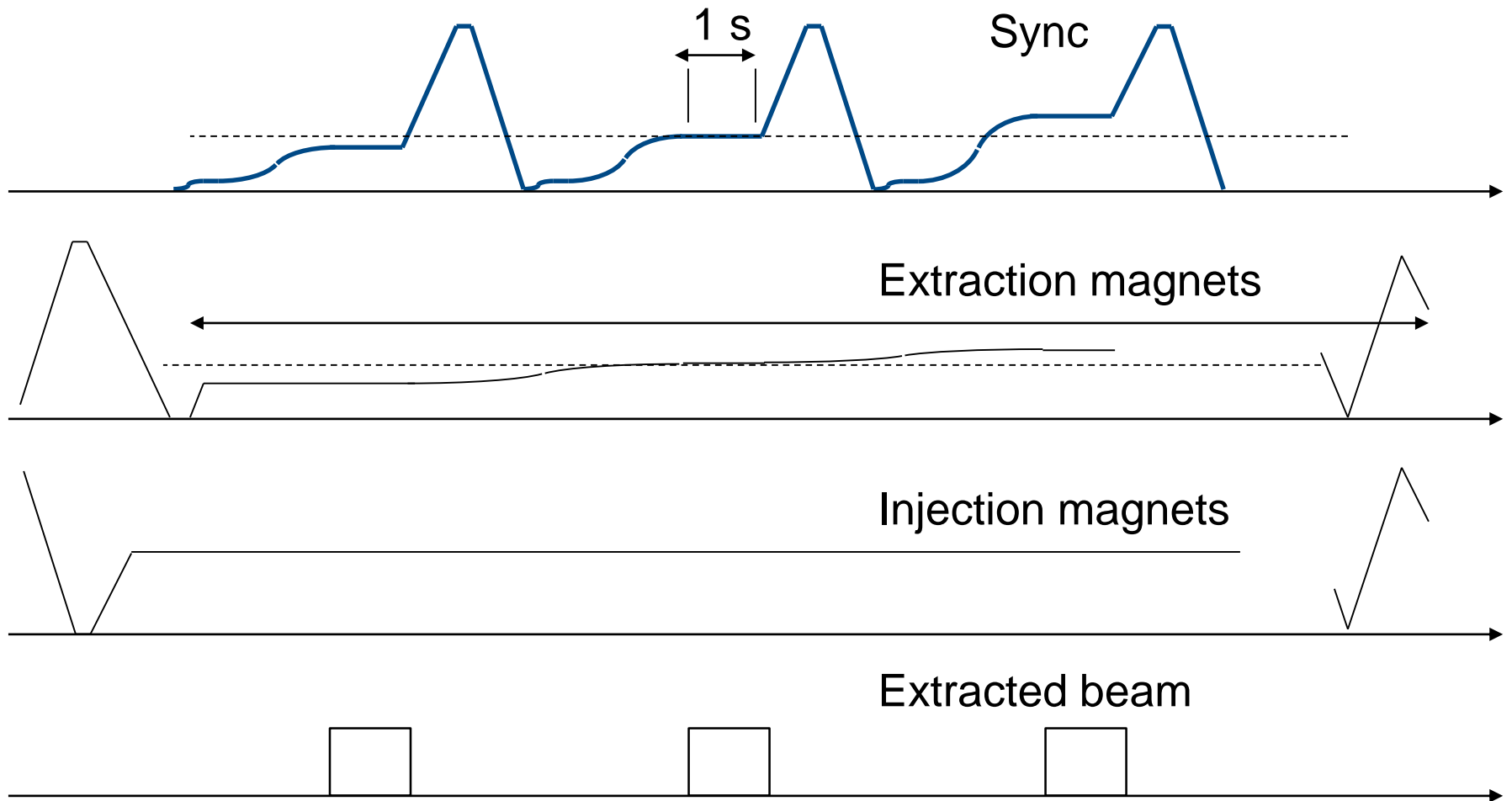
Additional ion species

Higher performances source

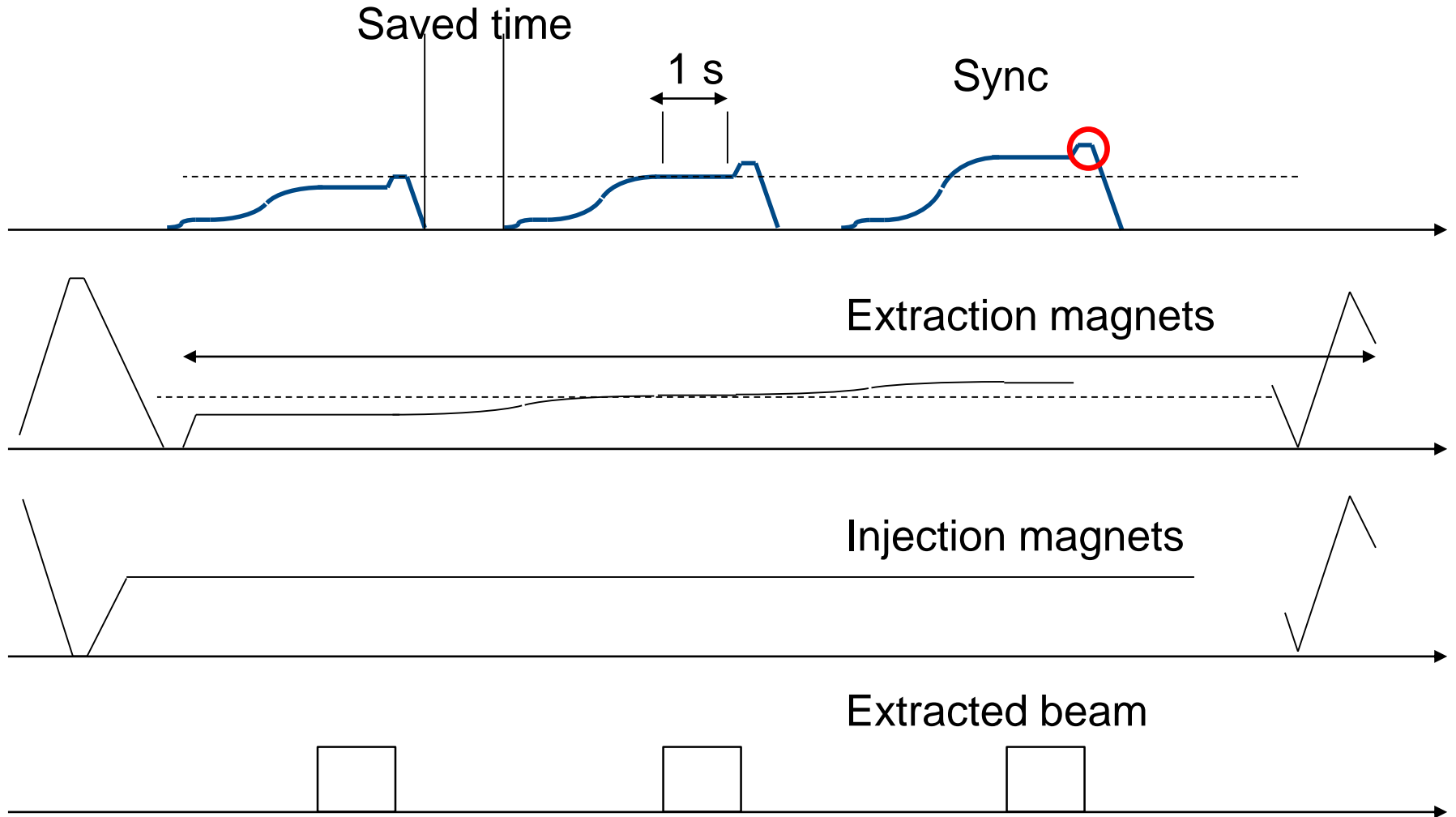
| Ion | SUPERNANOGAN (14.5 GHz) | AISHa (18 GHz + TFH) |
|---|-------------------------|----------------------|
| | [μ A] | [μ A] |
| H ⁺ | 2000 | 4000 |
| H ²⁺ | 1200 | 2000 |
| H ³⁺ | 800 | 1000 |
| ³ He ⁺ - ⁴ He ⁺ | 800 | 2000 |
| ¹² C ⁴⁺ | 200 | 800 |
| ⁶ Li ²⁺ | // | 600 |
| ¹⁸ O ⁶⁺ | 250 | 1000 |
| ¹⁶ O ⁶⁺ | 400 | 1200 |
| ²¹ Ne ⁷⁺ - ²⁰ Ne ⁷⁺ | | |



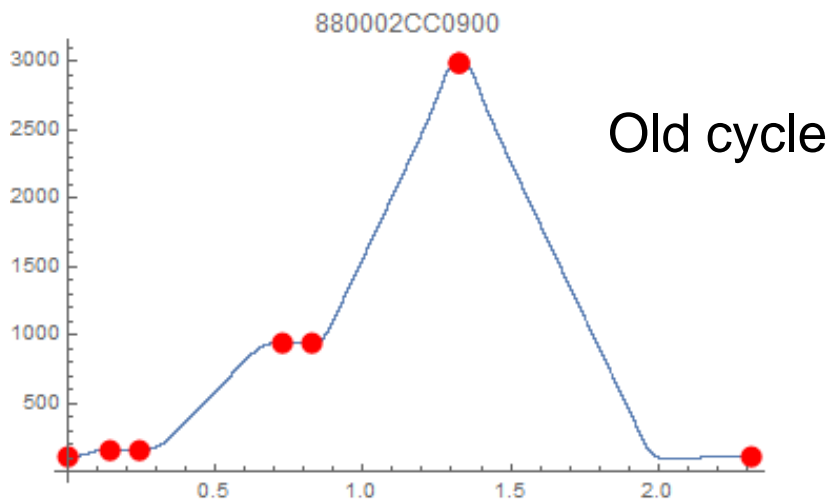
Treatment execution



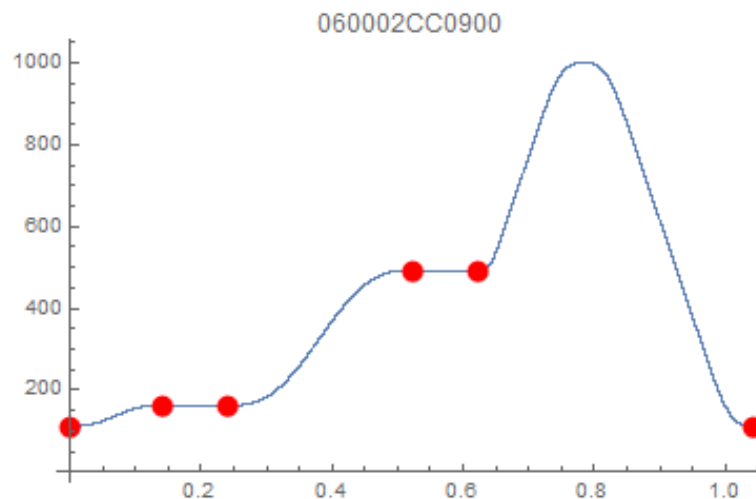
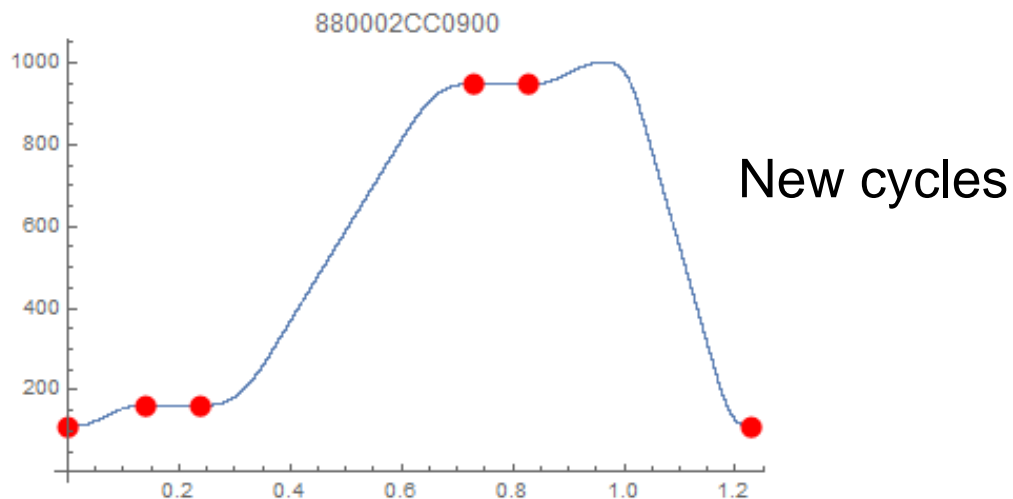
Dipole PS control in field

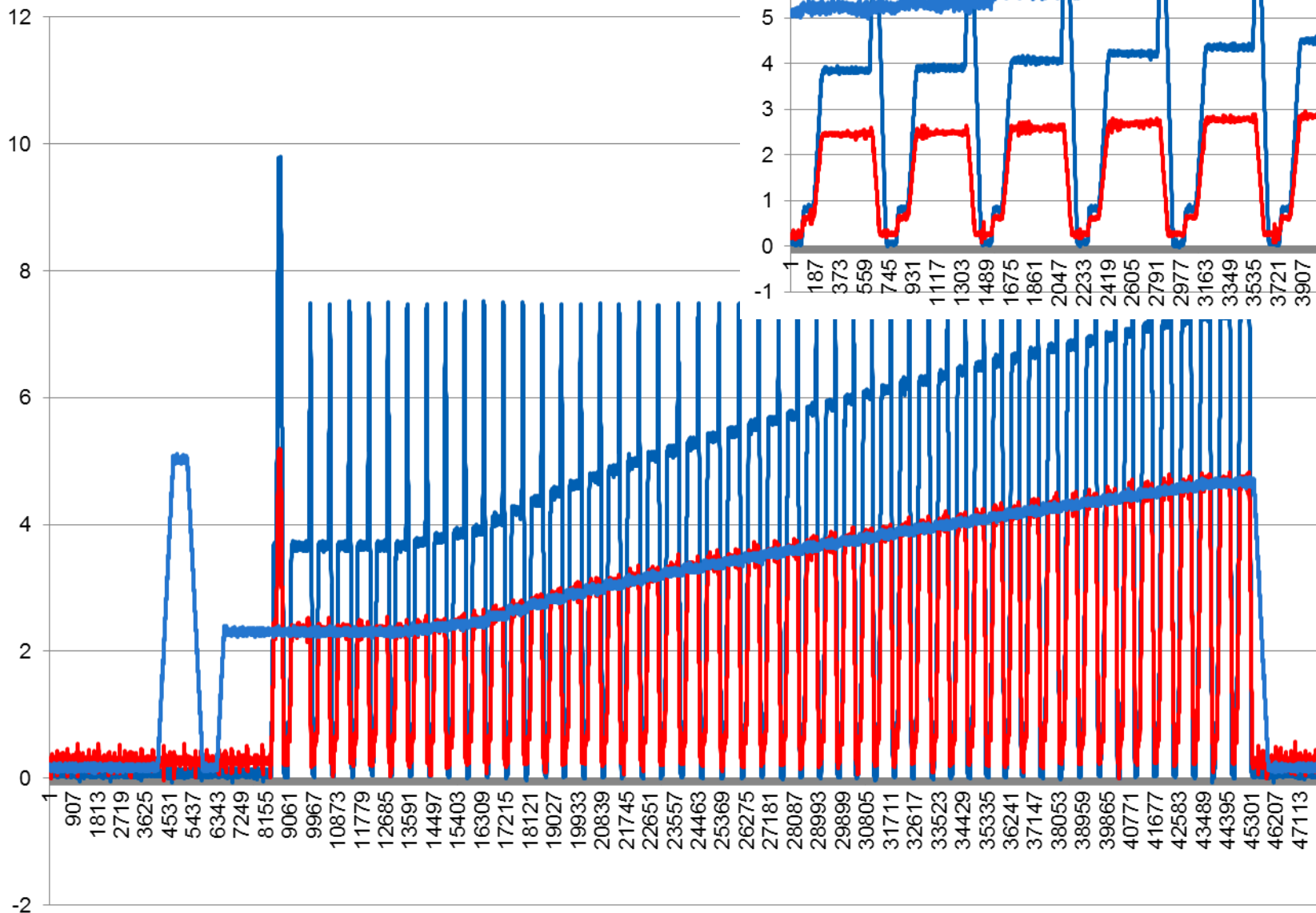


Other magnets short cycles

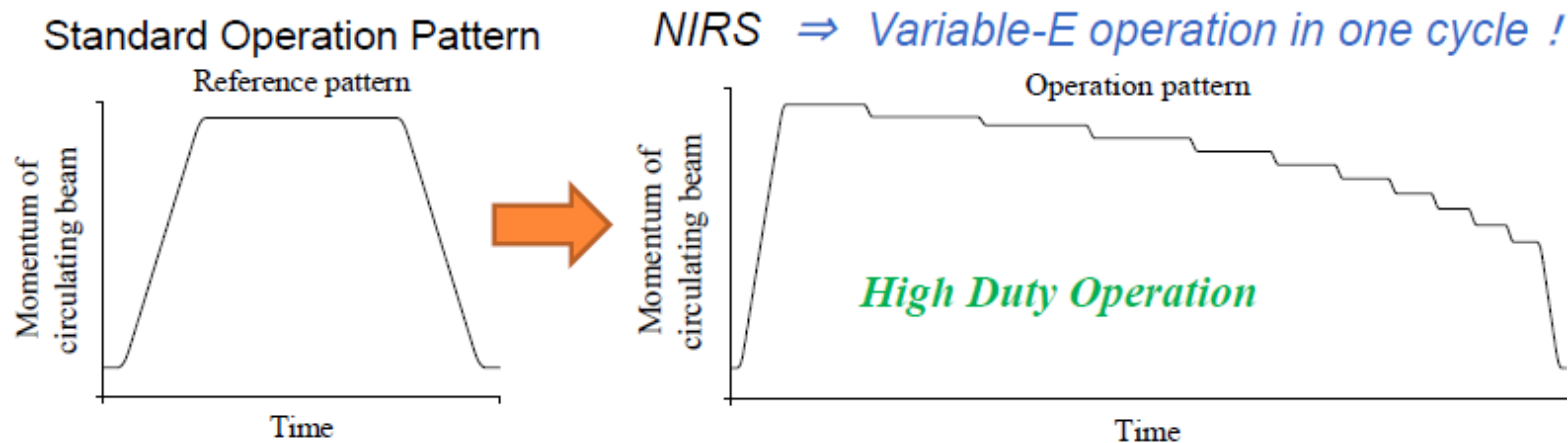


Ramp to lower I_{max}

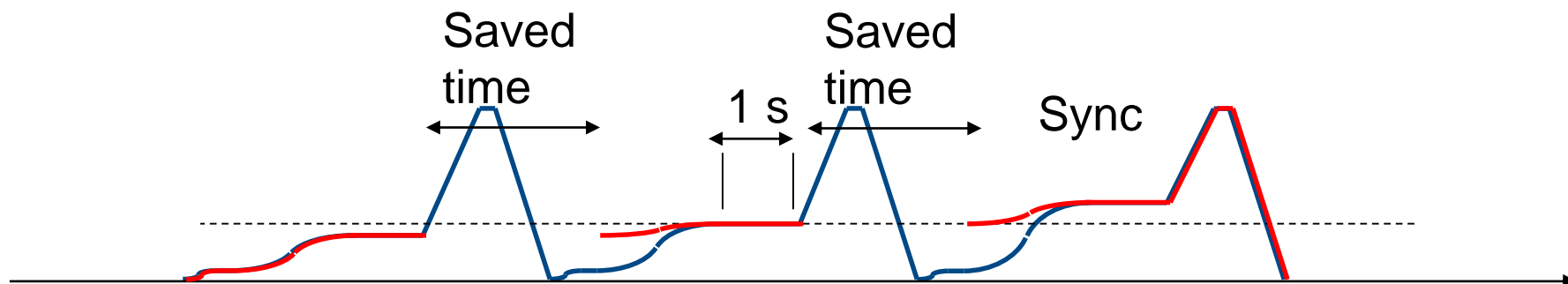




Treatment execution with Multi Energy Extraction



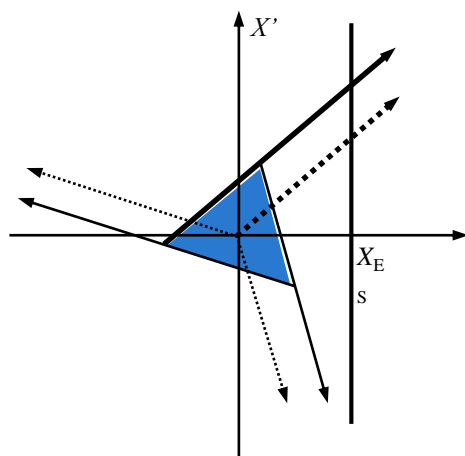
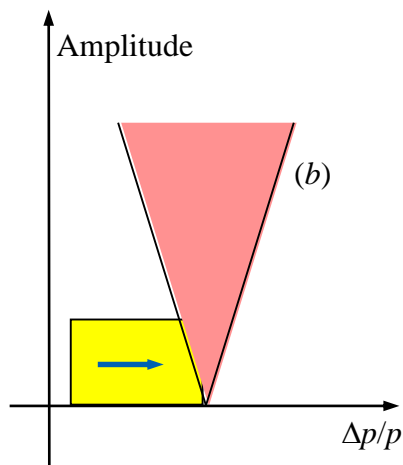
(Courtesy K. Noda – CAS Medical)



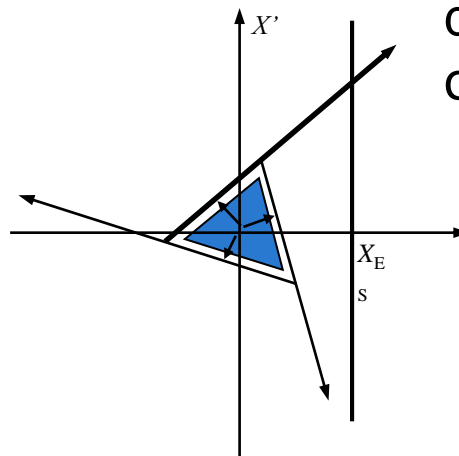
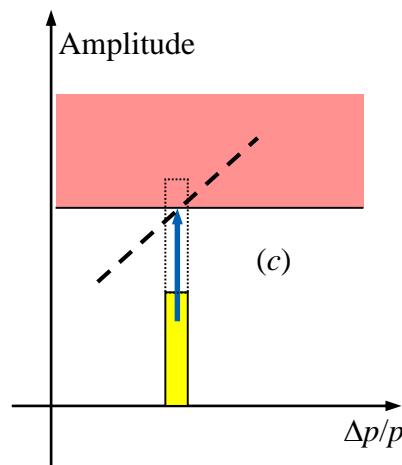
Implementation of RFKO in addition to betatron

Standard method
at CNAO

Amplitude-momentum
selection



RF-KO



Being implemented
for multi energy
extraction studies

direct comparison
of the two methods

RFKO implementation

RFKO Kicker just arrived

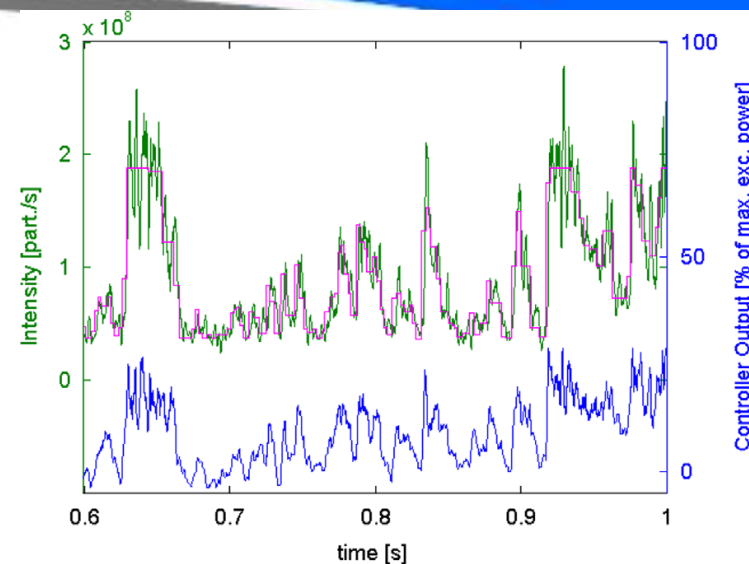
Installed in the synchrotron
but not yet operational



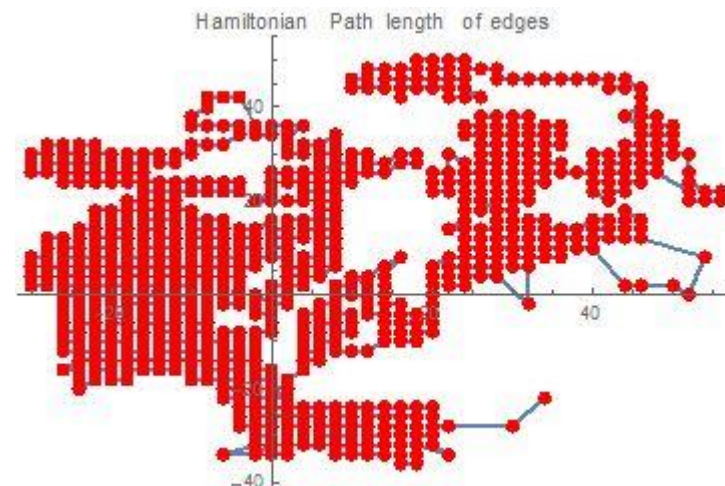
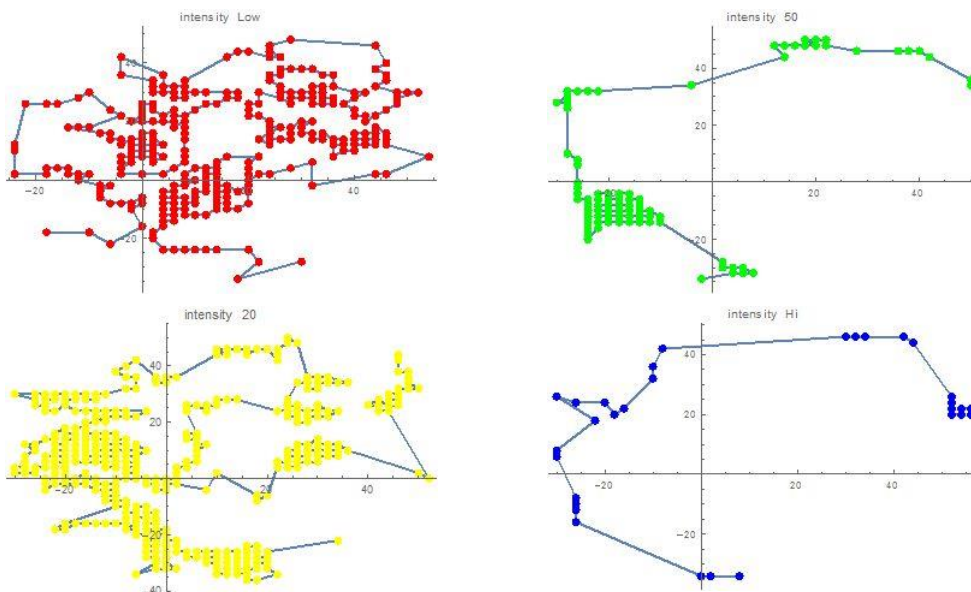
Intensity modulation for slow betatrons

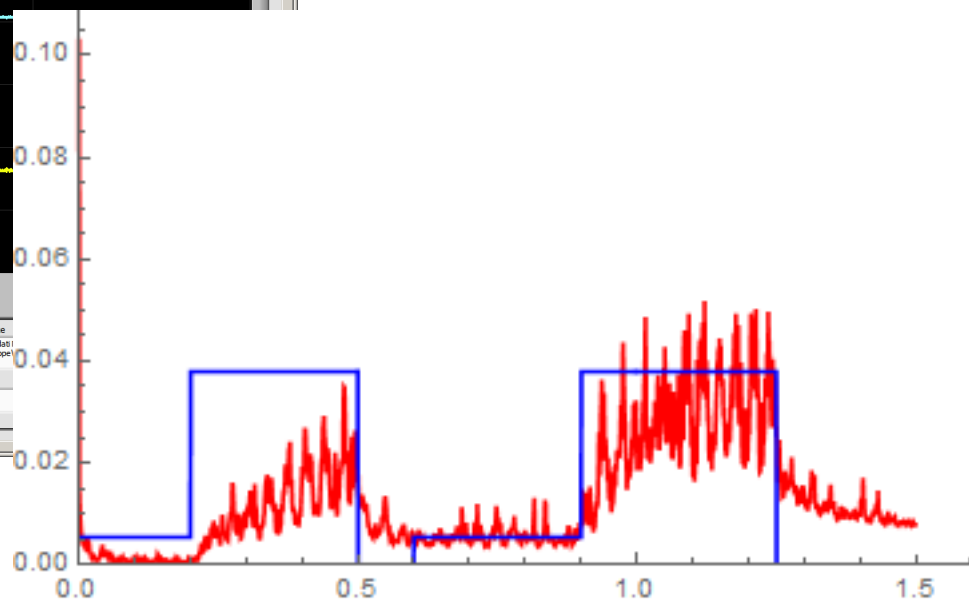
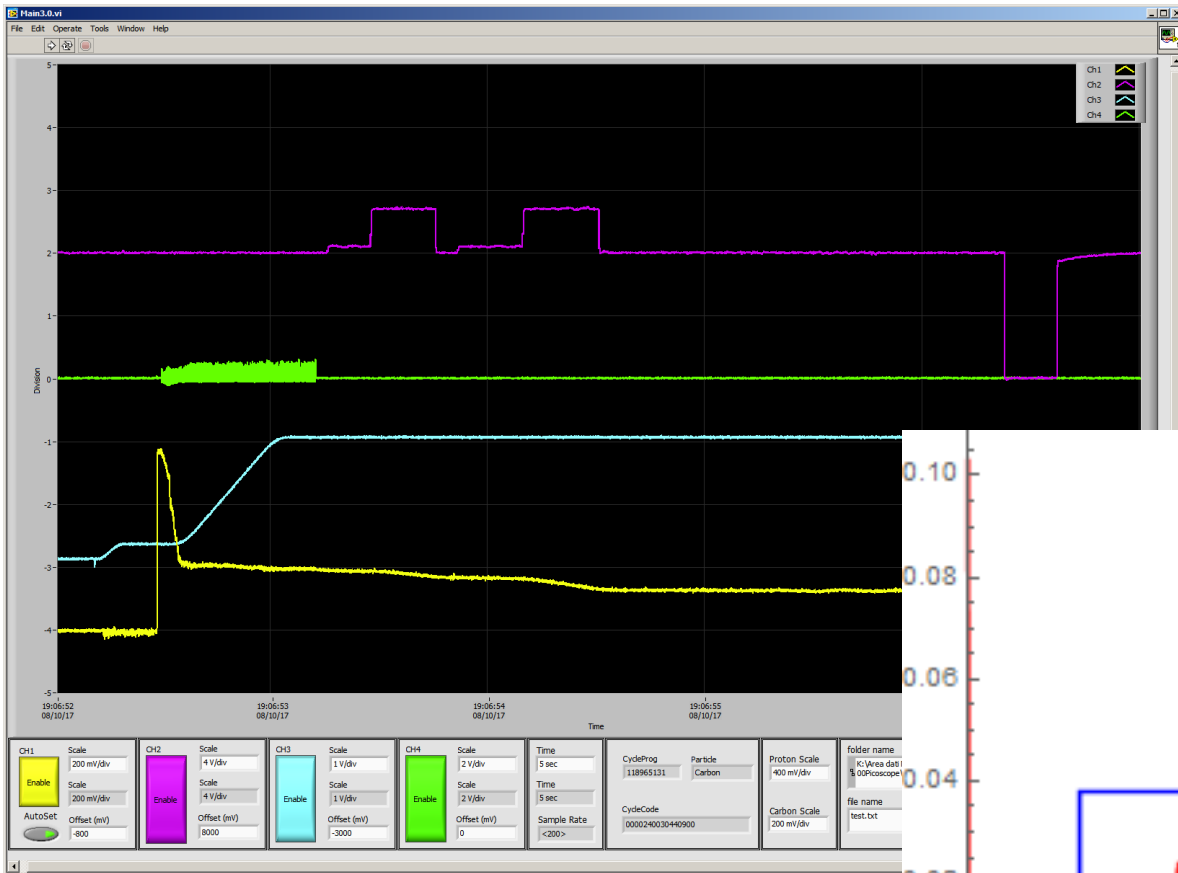
$N_{\max}/N_{\min} > 100$

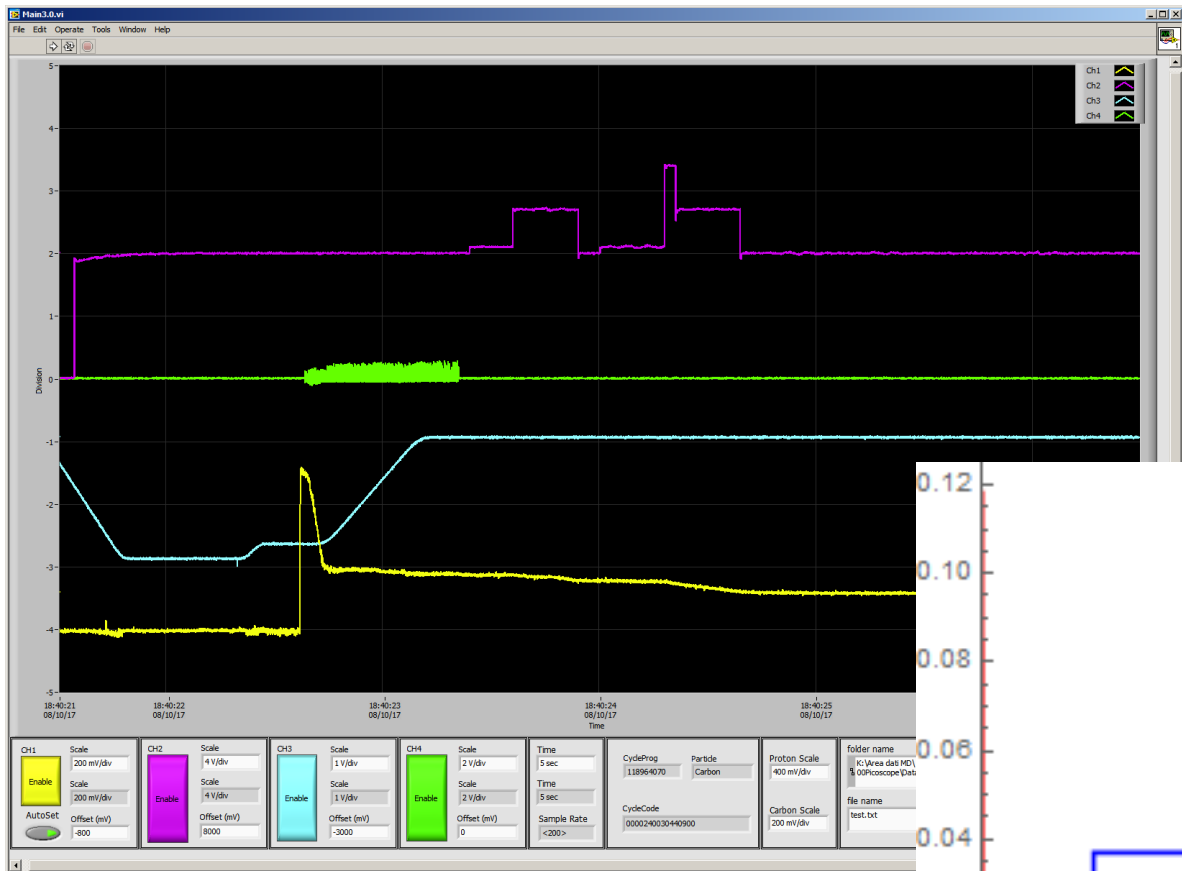
Subdivide voxels in classes and increase intensity during slice



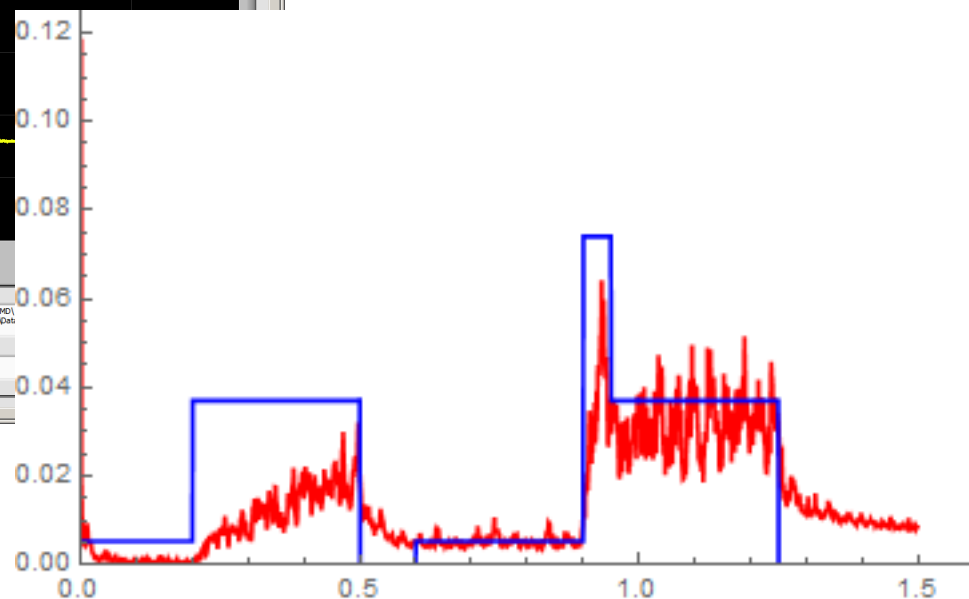
Schoemers et al, NIM A 795 (2015) 92-99



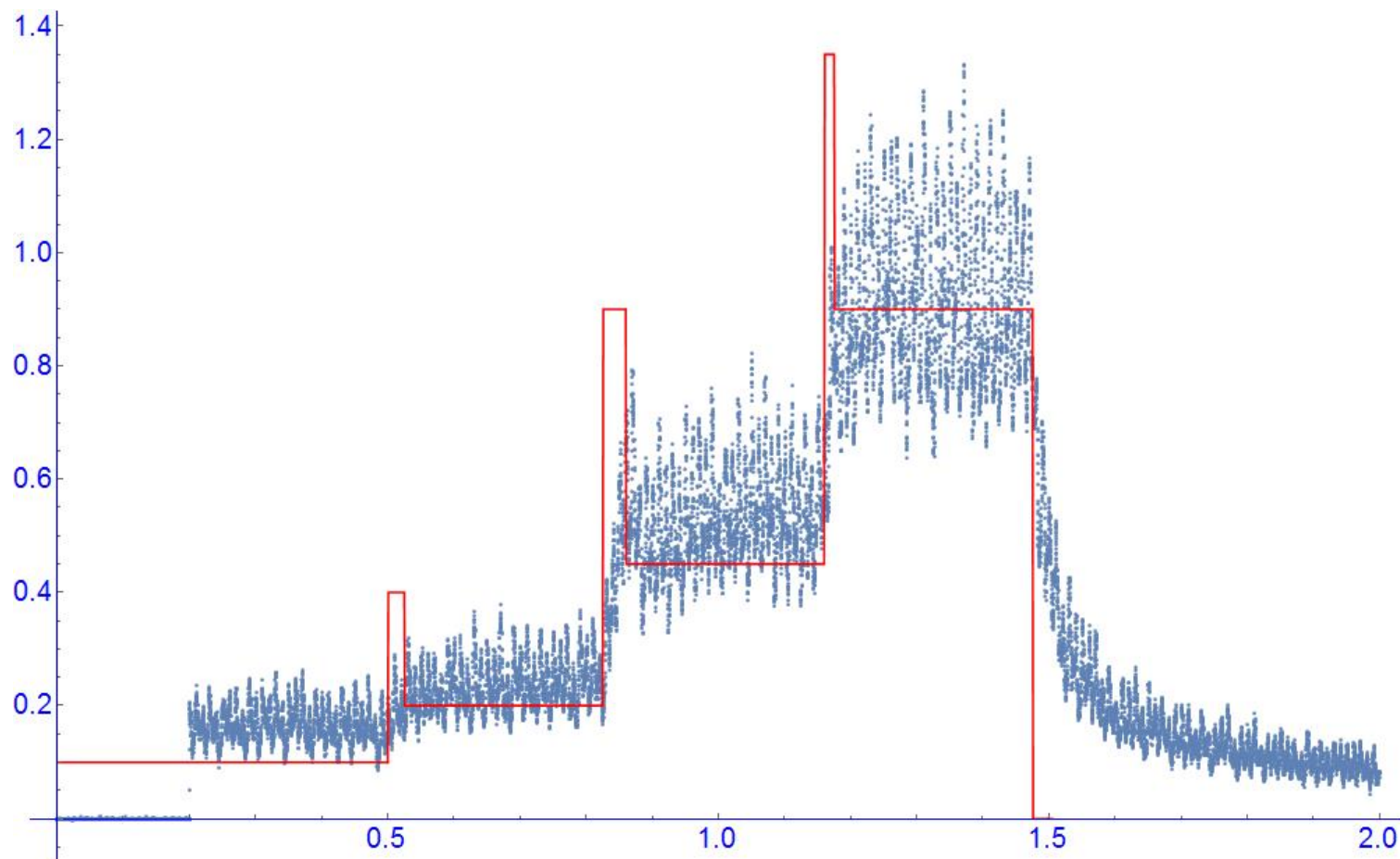




< 25 ms reasonable



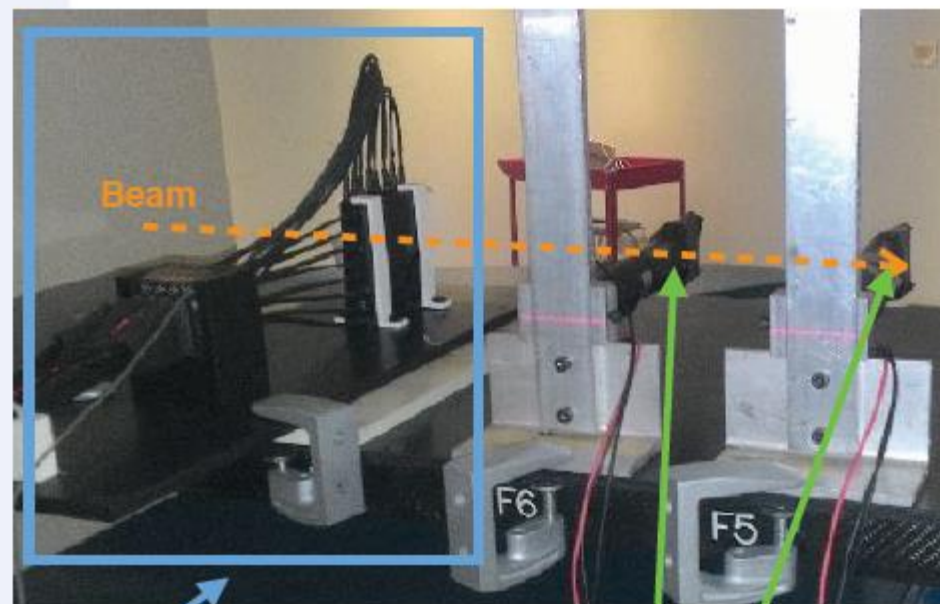
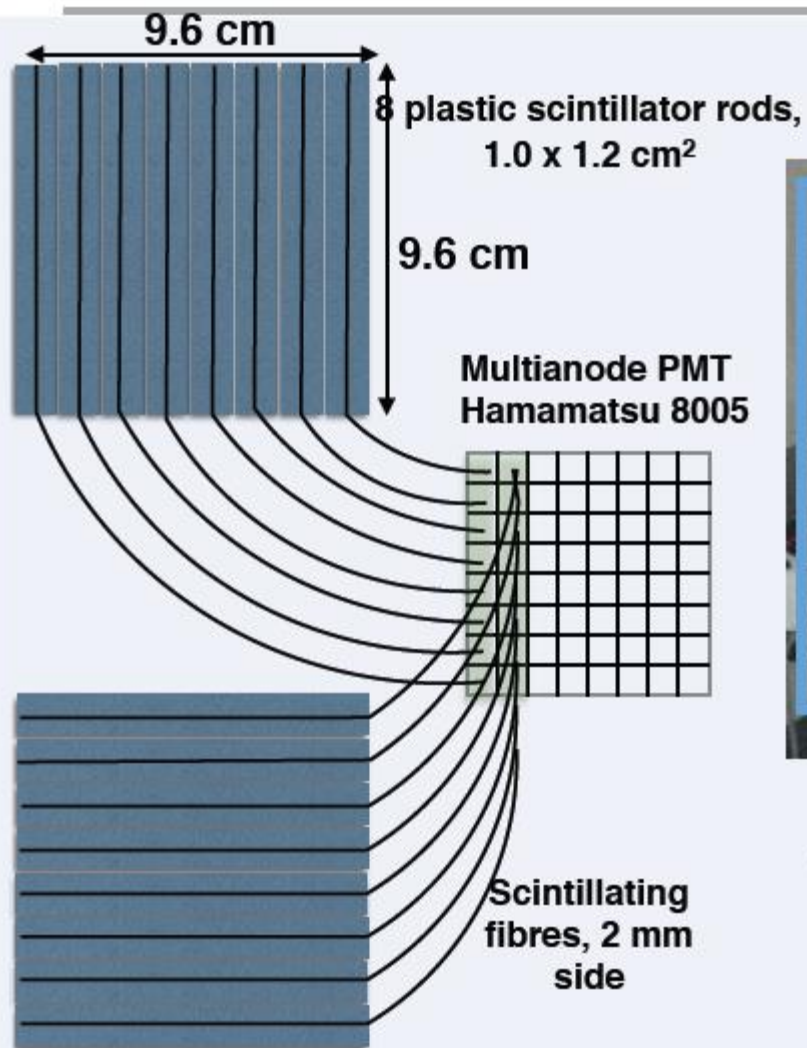
Intensity step up test



Low intensities

- For some applications like detector tests, some nuclear physics experiments (see FOOT exp.) a low intensity ($10^3 - 10^4$ particles/s) is required
- Such low intensities are out of the measurement range of the DDS
- A dedicated detector, capable to count the incoming ions and to monitor the beam position in the x-y plane, was provided by the Foot group (INFN - Roma - SBAI)

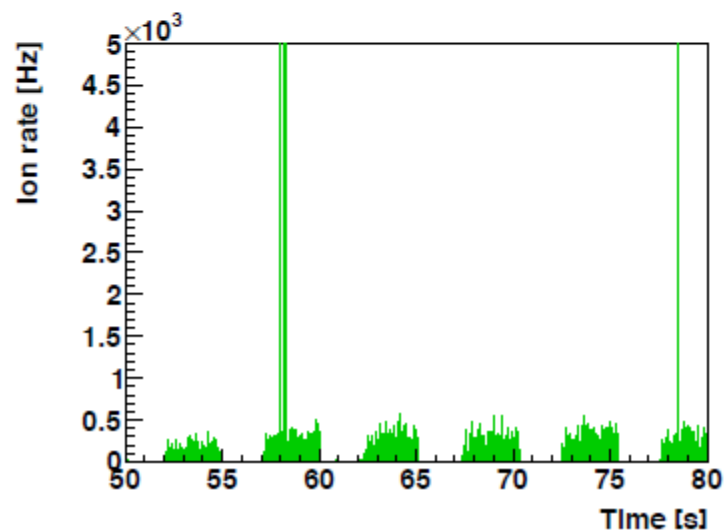
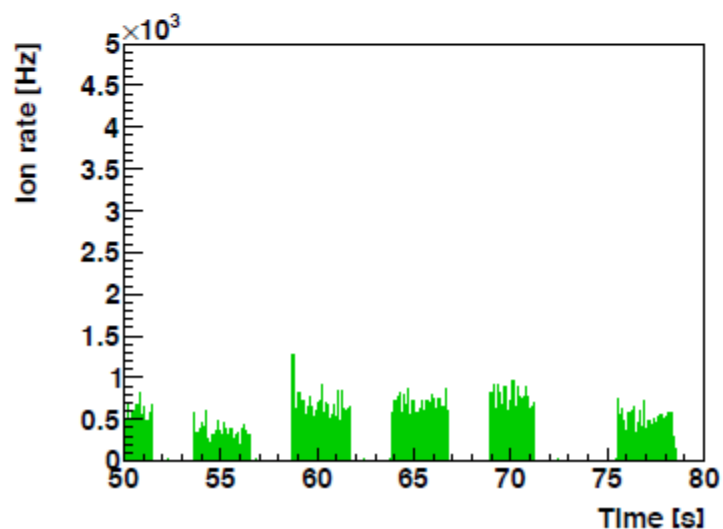
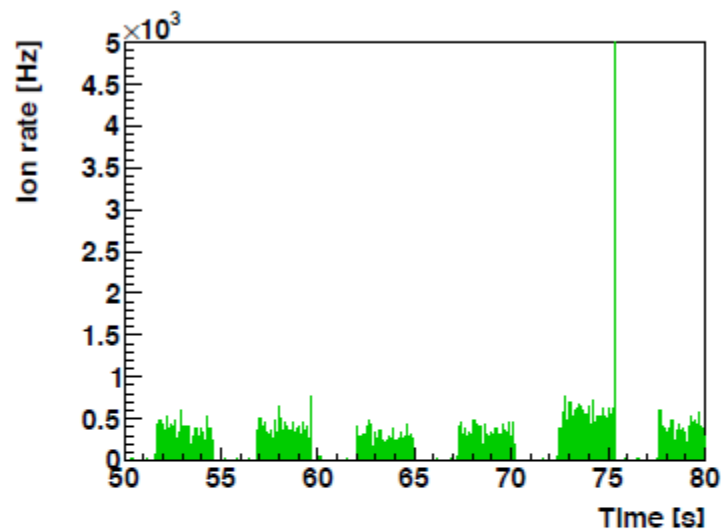
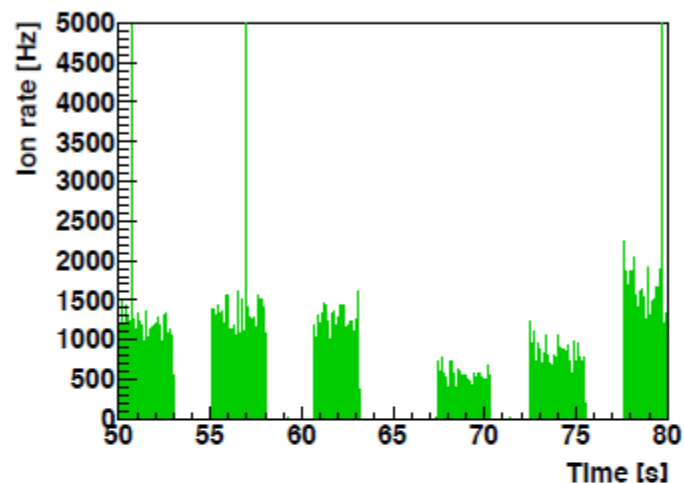
Experimental setup



Plastic scintillators
5x5x5 cm³ for efficiency
measurement

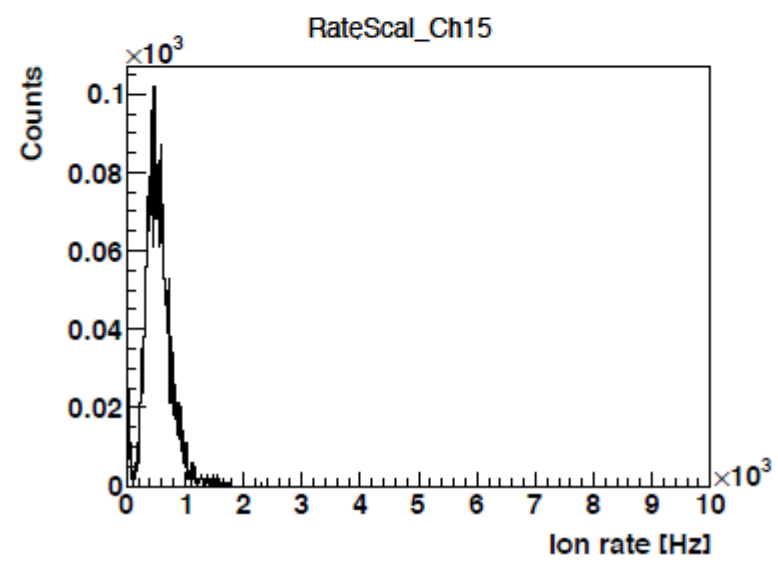
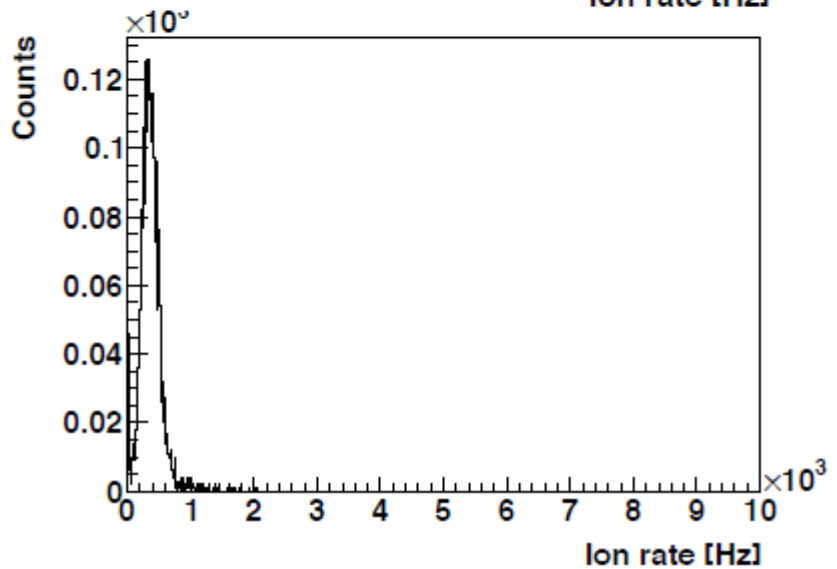
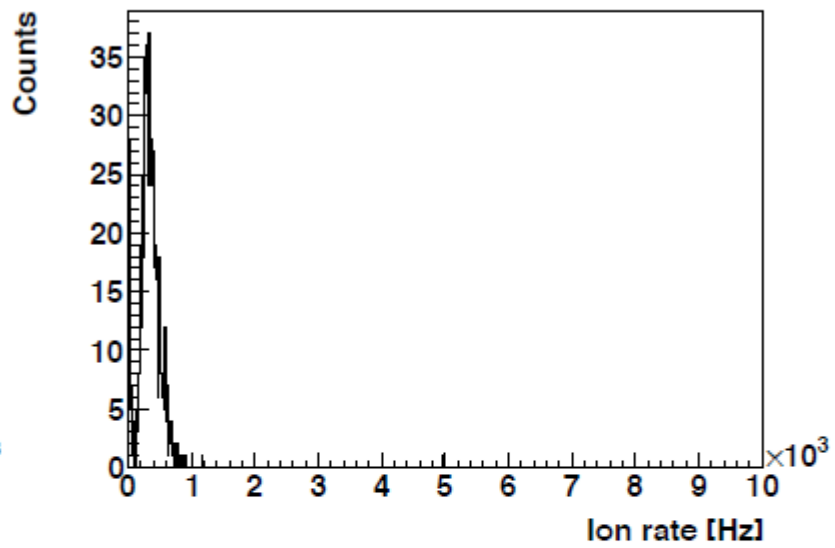
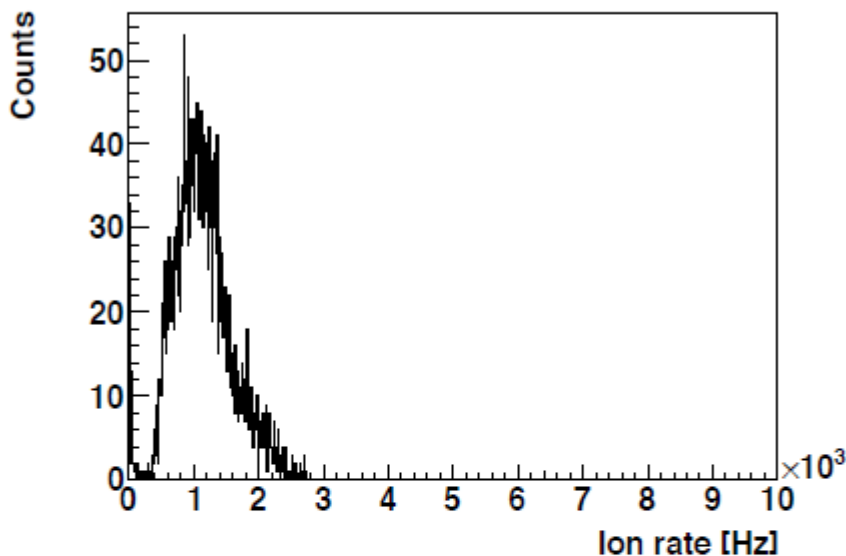
(Courtesy of Giacomo Traini)

Proton beam - Intensities vs time



(Courtesy of Giacomo Traini)

Proton beam - Intensity distribution



(Courtesy of Giacomo Traini)

What I would like in the next machine

- Just my opinion and wishlist

What I would like in the next machine

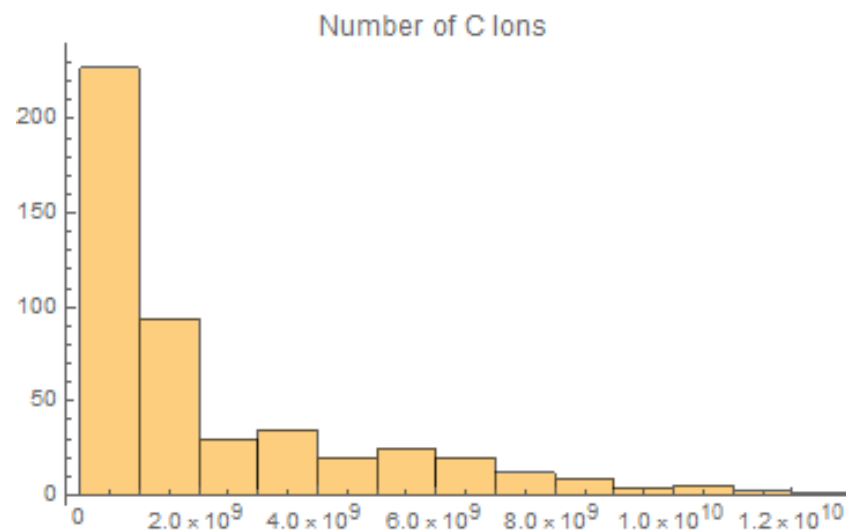
- Small
- Cheap
- Fast

What I would like in the next machine

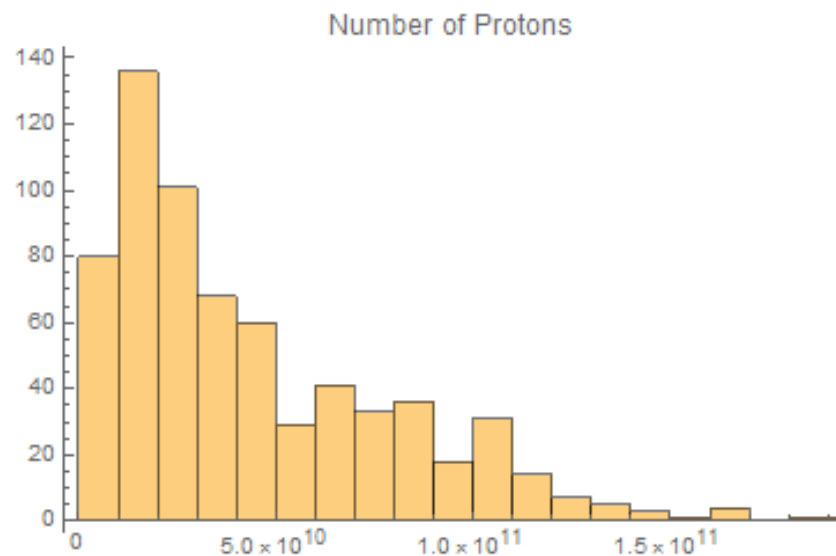
- Small
- Cheap
- Fast
- Large number of particles
(Multi En Ext)

Large number of accelerated particles

- Number of particles required in the fields delivered at CNAO last year



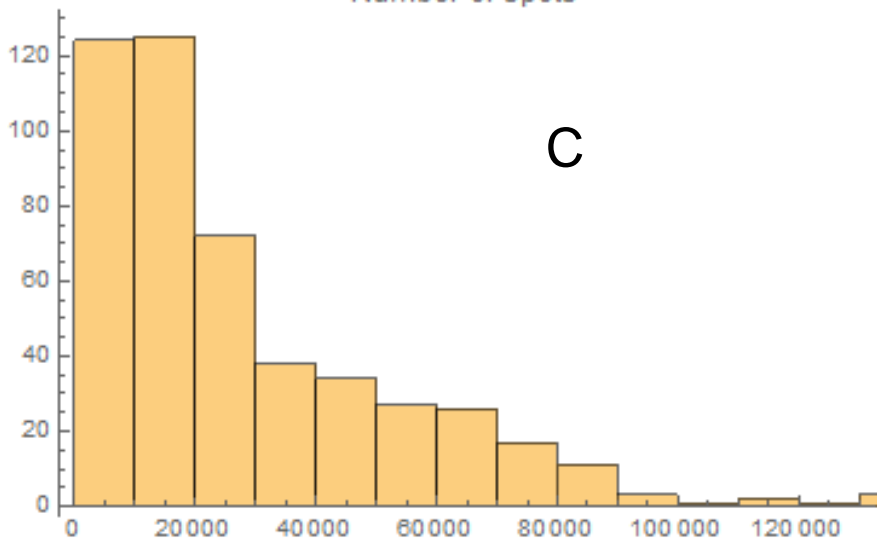
$$N_c = 1.5 \text{ E}10$$



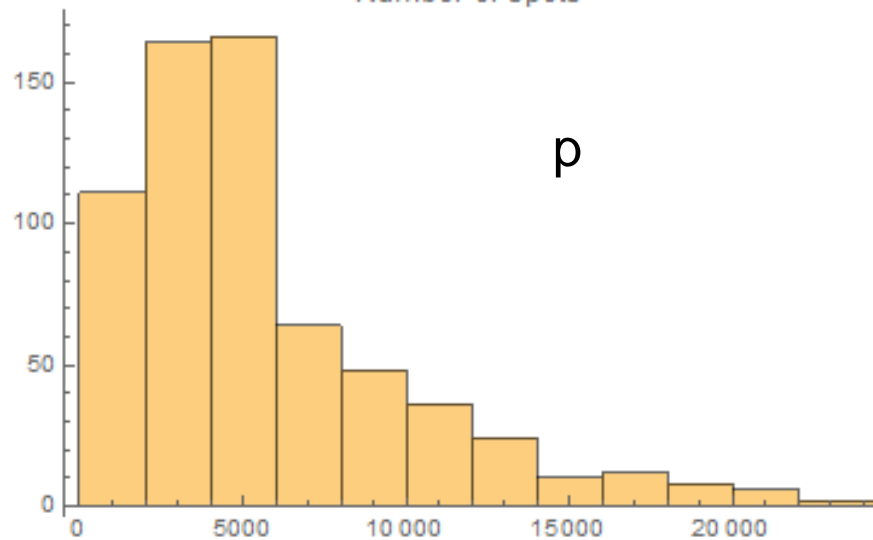
$$N_p = 2 \text{ E}11$$

Number of spots required in the fields delivered at CNAO last year

Number of spots



Number of spots



What I would like in the next machine

- Small
- Cheap
- Fast
- Large number of particles
(Multi En Ext)

What I would like in the next machine

- Small
- Cheap
- Fast
- Large number of particles
(Multi En Ext)
- Field control

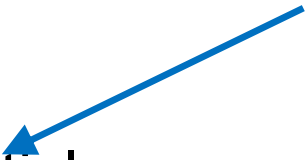
What I would like in the next machine

- Small
- Cheap
- Fast
- Large number of particles
(Multi En Ext)
- Field control
- Dose driven DDS (fast)
- Large range DDS

What I would like in the next machine

- Small
- Cheap
- Fast
- Large number of particles
(Multi En Ext)
- Field control
- Dose driven DDS (fast)
- Large range DDS
- Get rid of the LINAC?
(KEK DA style)

What I would like in the next machine

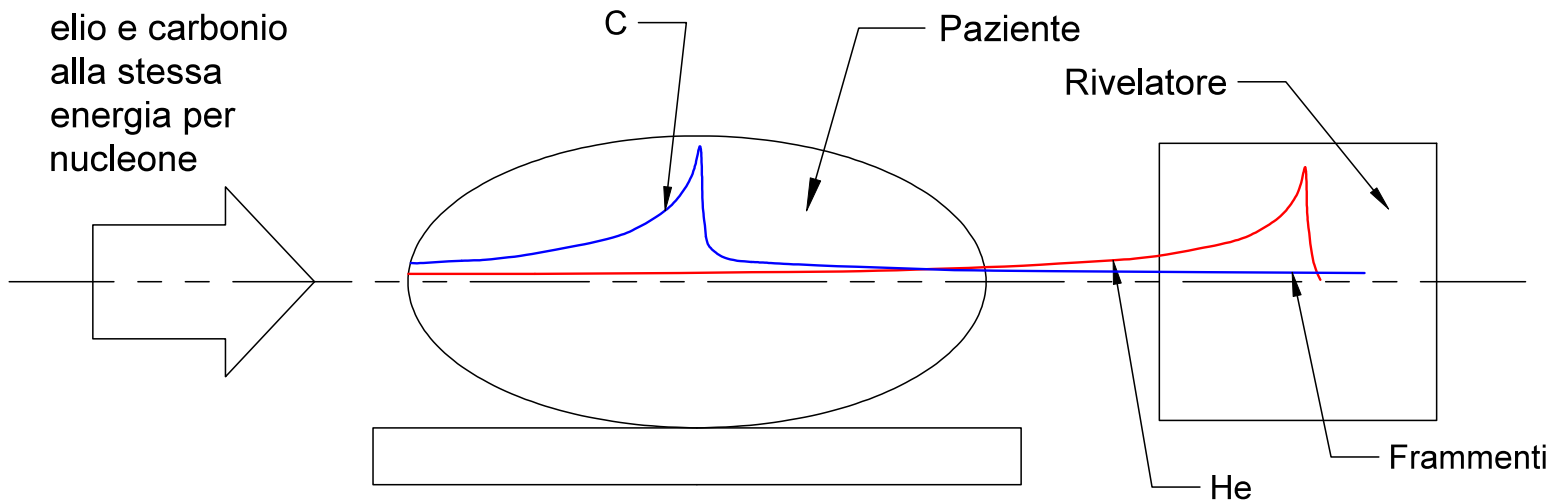
- Small
 - Cheap
 - Fast
 - Large number of particles (Multi En Ext)
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- Get rid of the LINAC? (KEK DA style)
 - C⁶⁺ source
- 

What I would like in the next machine

- Small
- Cheap
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- Large range DDS
- Get rid of the LINAC? (KEK DA style)
- C⁶⁺ source
- LINAC for A/Q=4 for HeCheck

HeCheck

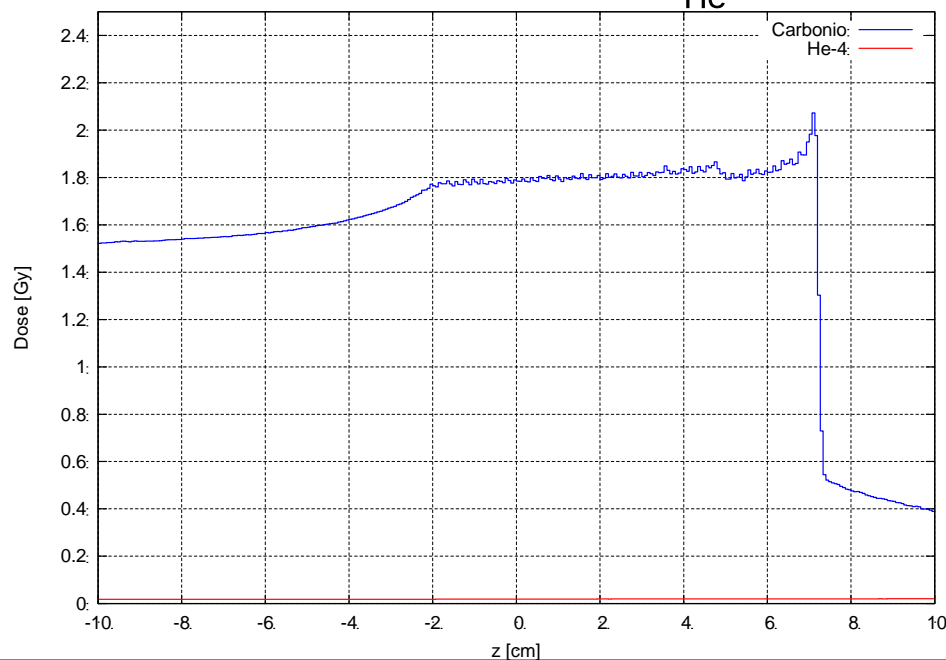
Fascio misto di elio e carbonio alla stessa energia per nucleone



Proof of principle

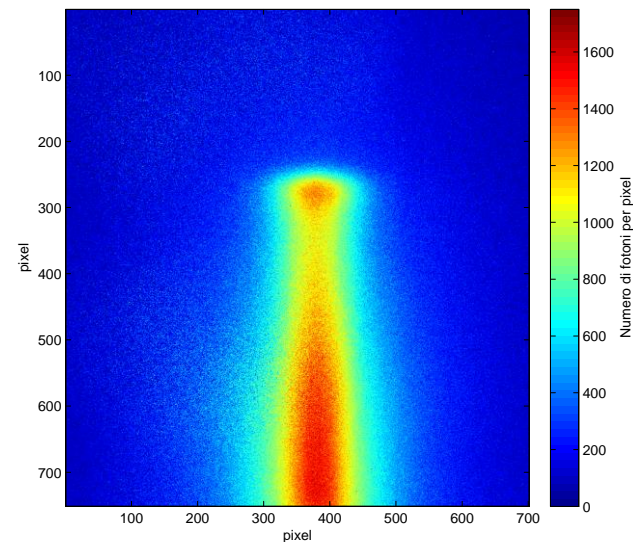
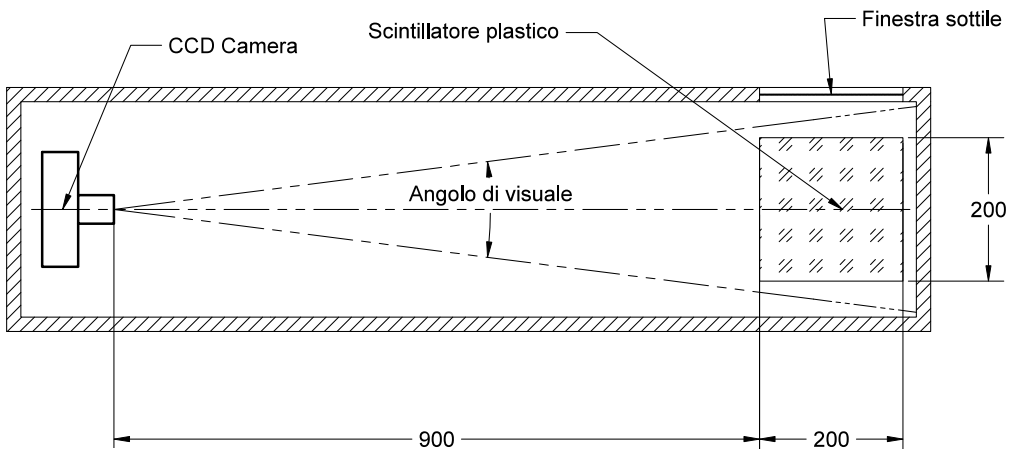
He 10% in number wrt C

1% in dose

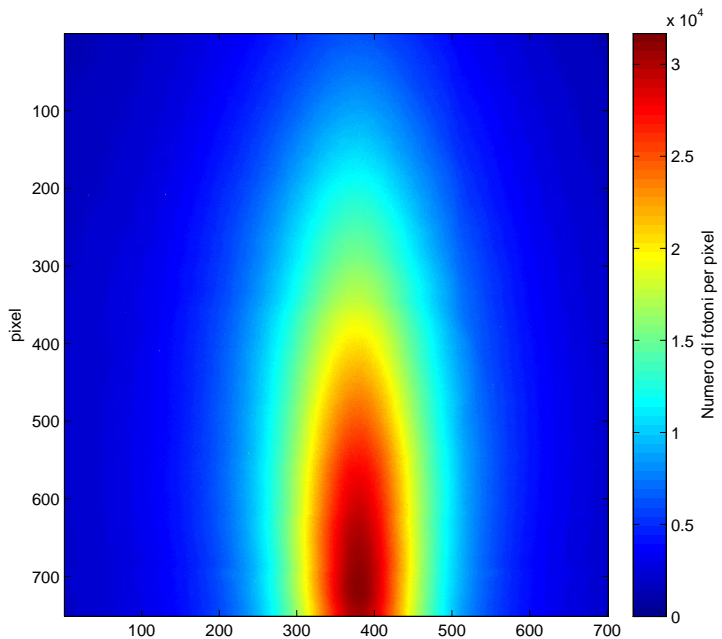


(Courtesy of D. Mazzucconi)

HeCheck

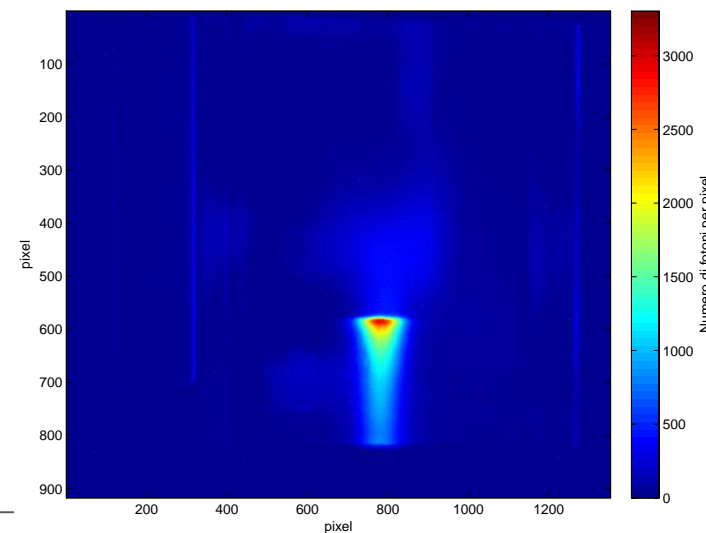


Protoni (5×10^5) da 226.5 MeV e carbonio (5×10^6) alla stessa energia per nucleone.



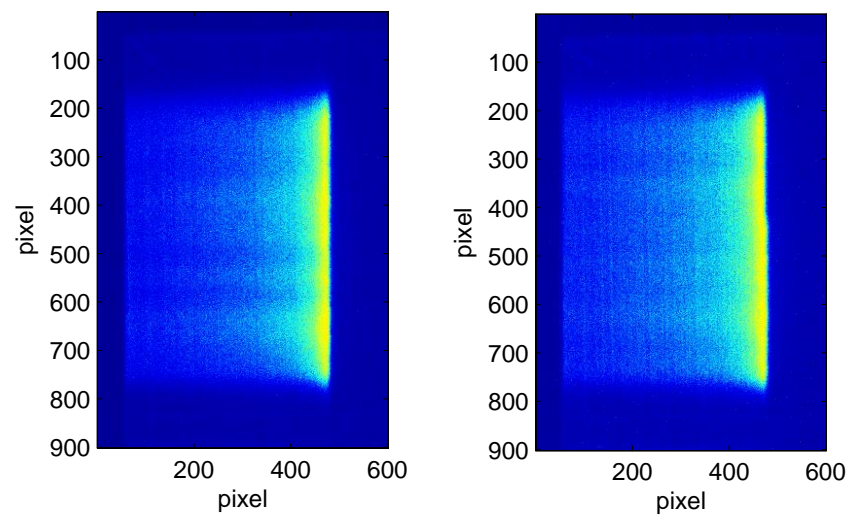
Frammenti da carbonio da 280 MeV/u e 5×10^7 primari.

Protoni da 81 MeV e 5×10^5 primari.



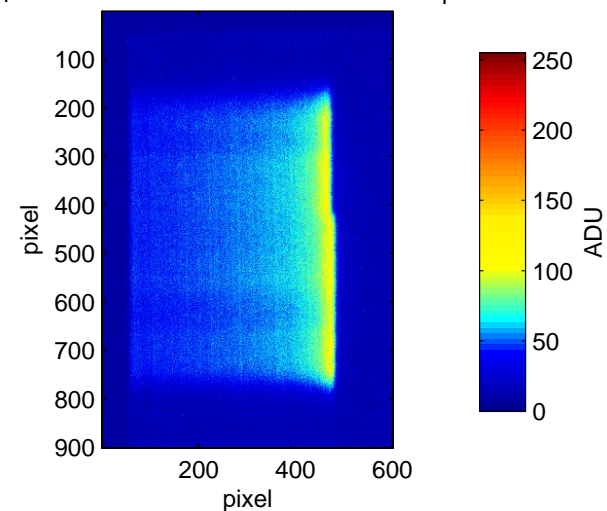
(Courtesy of D. Mazzucconi)

Resolution < 1 mm



(Courtesy of D. Mazzucconi)

| Posizione n° | Range misurato senza slab [mm] | Range misurato con slab da 1mm [mm] | Range misurato con slab da 2mm [mm] |
|--------------|--------------------------------|-------------------------------------|-------------------------------------|
| 1. | 100.524 | 99.244 | 98.732 |
| 2. | 100.524 | 99.244 | 98.476 |
| 3. | 100.524 | 99.500 | 98.732 |
| 4. | 100.524 | 99.244 | 98.732 |
| 5. | 100.524 | 99.500 | 98.732 |
| 6. | 100.524 | 99.500 | 98.732 |
| 7. | 100.524 | 100.268 | 100.268 |
| 8. | 100.524 | 100.268 | 100.780 |
| 9. | 100.524 | 100.524 | 100.780 |
| 10. | 100.524 | 100.268 | 100.780 |
| 11. | 100.524 | 100.524 | 100.780 |
| 12. | 100.524 | 100.268 | 100.780 |
| 13. | 100.524 | 100.524 | 100.524 |
| 14. | 100.524 | 100.268 | 100.524 |
| 15. | 100.268 | 100.012 | 100.524 |



What I would like in the next machine

- Small
- Cheap
- Fast
- Large number of particles (Multi En Ext)
- Field control
- Dose driven DDS (fast)
- Large range DDS
- Get rid of the LINAC? (KEK DA style)
- C⁶⁺ source
- LINAC for A/Q=4 for HeCheck
- ¹¹C source?

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- ¹¹C source?
- Gantry (small, cheap...)

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- Dose driven DDS (fast)
- Large range DDS
- Get rid of the LINAC? (KEK DA style)
- C⁶⁺ source
- LINAC for A/Q=4 for HeCheck
- ¹¹C source?
- Gantry (small, cheap...)
- Experimental room

What I would like in the next machine (cont)

- Multi ion
- Multi ion treatment (fast particle switch)
- Larger field to avoid patching (increase N_p and N_c ?)
- Hypofractionation (increase N_p and N_c ?)
- 3D Tracking
- Real time imaging (at least pre treatment He radiograph)
- Simple operation but with R&D and upgrade possibility
- safety, efficiency, reliability, maintainability



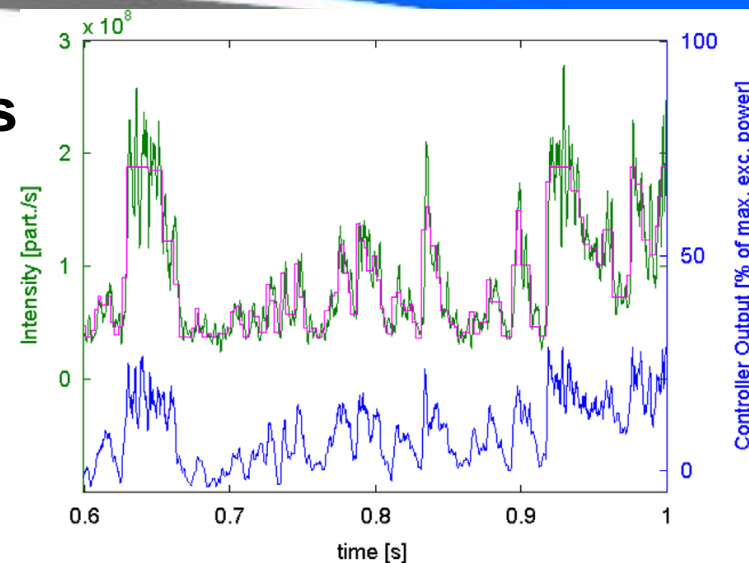
Thank you for your attention

“Physics is like sex: sure, it may give some practical results, but that's not why we do it.”

R. Feynmann

Intensity modulation for slow betatrons

Subdivide voxels in classes and increase intensity during slice



Schoemers et al, NIM A 795 (2015) 92-99

