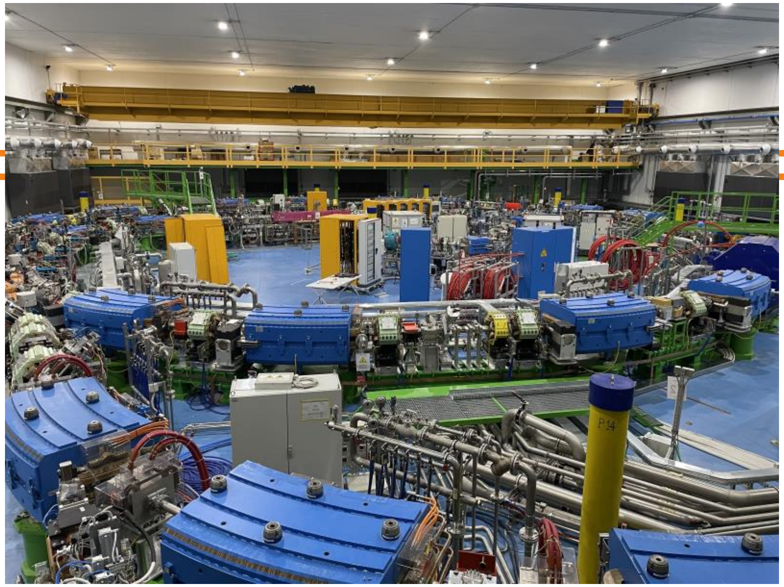
Collaboration topics
Between CNAO and IN2P3 partners

- INFN, Politecnico Milano, Pavia Hospital…
- CNRS-INSB (Biology), CNRS-INS2I and INSIS (Computing, Imaging)

D. Dauvergne, June 24, 2022

Centro Nazionale di Adroterapia Oncologica



- CNAO :
  - Protons 60-250 MeV – ~10^{10} p/spill
  - Ions ^{12}C 120-400 MeV/u - ~10^{8} C/spill
  - Next (2023): ^{4}He, ^{7}Li, ^{16}O, (^{56}Fe)

- Experimental room equipped with scanning

Status about additional collaboration topics

- Several meetings coordinated by M. Pullia and M. Vanstalle in 2022

  - Beam monitoring – Prompt Gamma imaging
  - BNCT – neutron measurements
  - Moving organs
  - Accelerators

- Objective: treatment quality optimization

  - Improve precision of TPS
  - Online control of the treatment

Beam monitors for timing applications

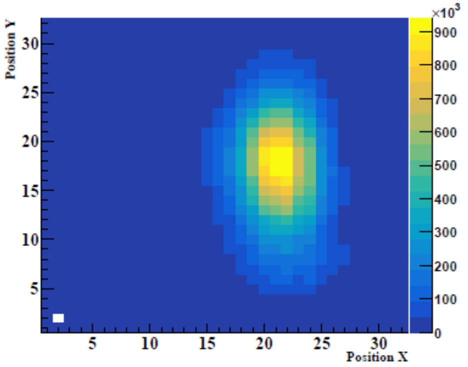
- Protons: 10^9 – 10^{10} – p/s, uniform distribution during 1-3 s spill
- Carbon: 10^7- 10^8 ions/s: single ion identification possible

- CLaRyS-IN2P3: scintillating-fiber hodoscope

(IP2I-LPSC-CPPM-CREATIS)

  - 2x128 fibers X,Y, 1 mm^2 square section
  - Readout MA-PMT (512 channels)
  - ASIC Front-end, fast AMC-40 acquisition

  → tested at CAL-Nice (65 MeV protons)



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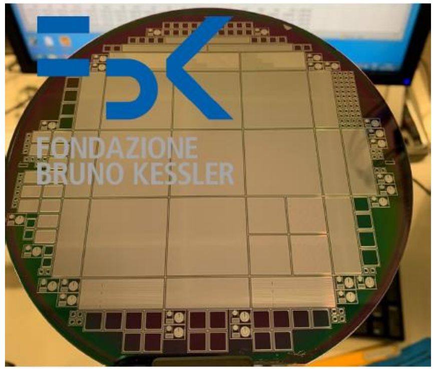
- INFN-Torino: LGAD sensors

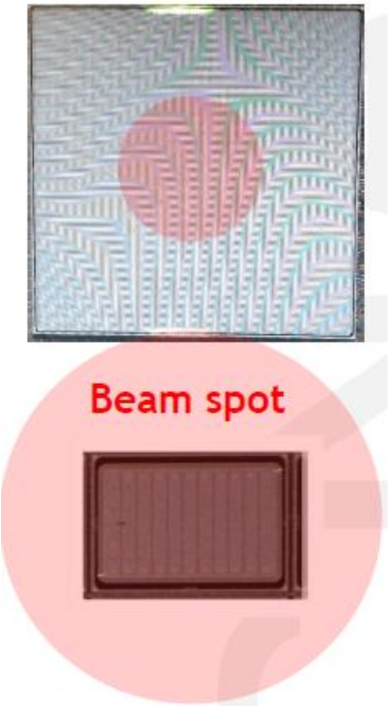


Detectors for proton counting

- Large area (2.7×2,7 cm^2)
- 146 strips

Detectors for timing applications

- Smaller size, 11 strips
- Si- substrate removed to reduce total thickness to 70 µm



R. Sacchi, INFN- Univ Torino

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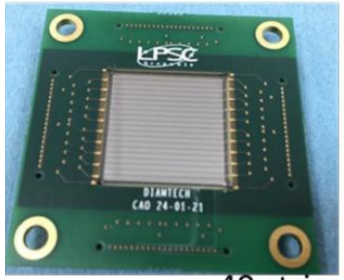
~1cm² matrix single-crystal diamond

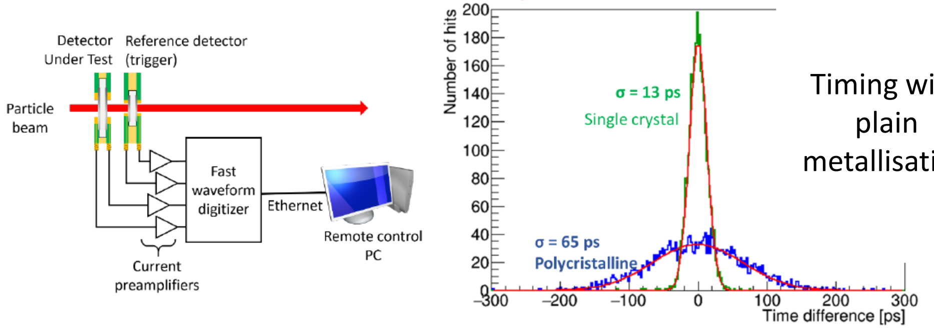
1 pCVD = 4 cm²



40 strips

polycrystal diamond

Beam tests in GANIL with 95 MeV/u carbon beam



Timing with plain metallisation

S. Curtoni et al, NIM A, Elsevier,2021, 1015, pp.165757. ;10.1016/j.nima.2021.165757

Beam monitors for timing applications

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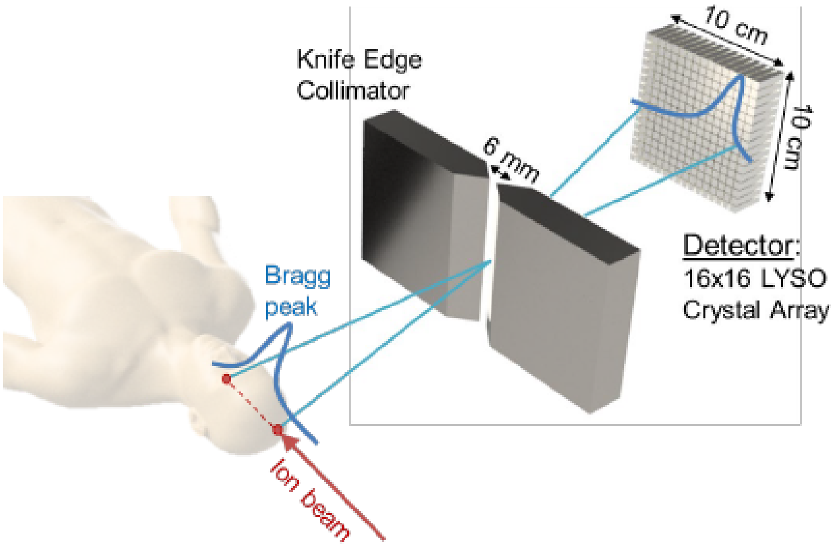
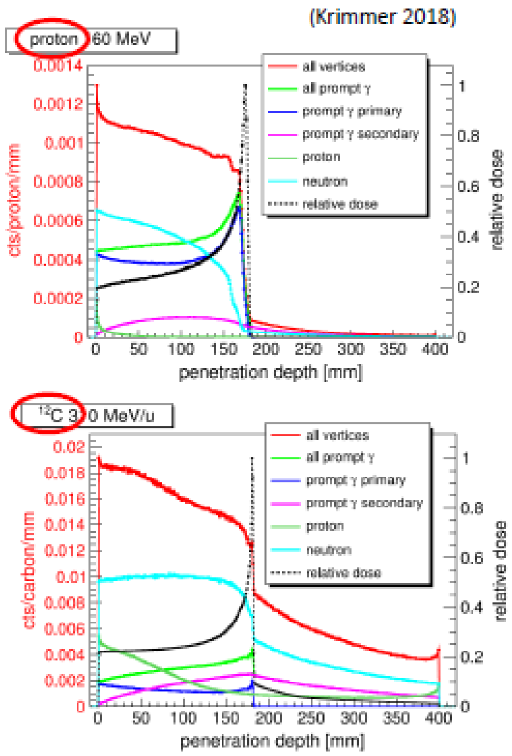
- Fast front-end and acquisition electronics on both sides
  - Common developments?
  - Common tests - comparisons

Online control of the range using prompt-gammas

Study of PGI with carbon irradiation at CNAO





Challenges:

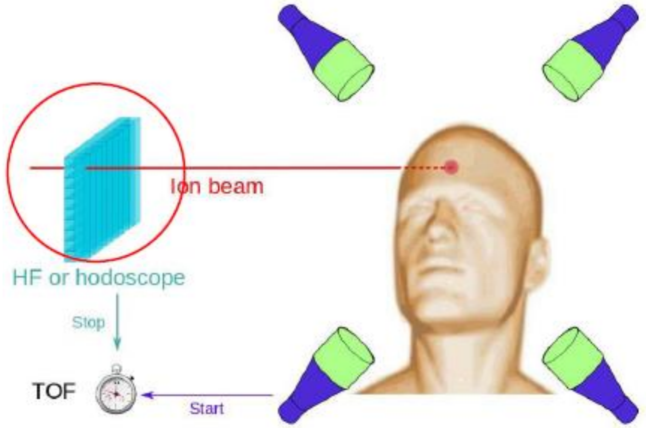
- Two orders of magnitude less carbon ions than protons used for irradiation (issue partially compensated by higher PG yield of carbon vs. proton)
- Secondary gammas reduces the range-end falloff
- Higher neutron background (vs. proton irradiation)

Carlo Fiorini – Politecnico di Milano and INFN, Italy 5

Strategy: neutron gamma discrimination - pulse-shape analysis

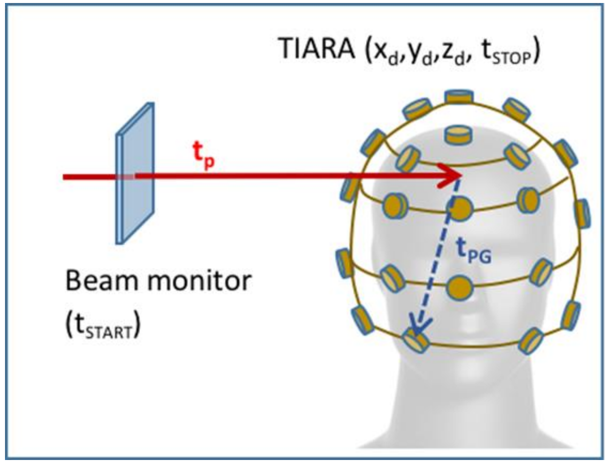
Online control of the range using prompt-gammas

- Prompt-Gamma Peak Integral
  IN2P3-CLaRyS collaboration
  Statistical determination of path position/length
  TOF used to select PG from patient



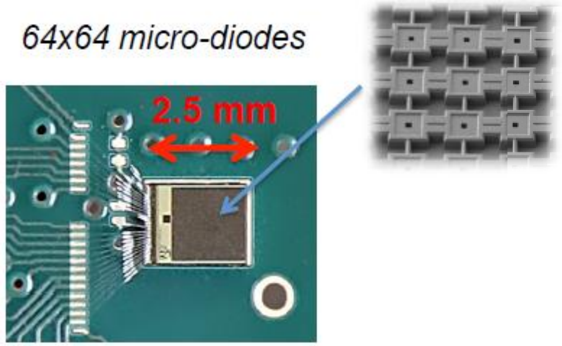
- Prompt-Gamma Timing Imaging
  IN2P3-TIARA collaboration (LPSC-CPPM-CAL Nice)
  TOF-based Imaging beam range
  - Fast Cerenkov + SiPM readout

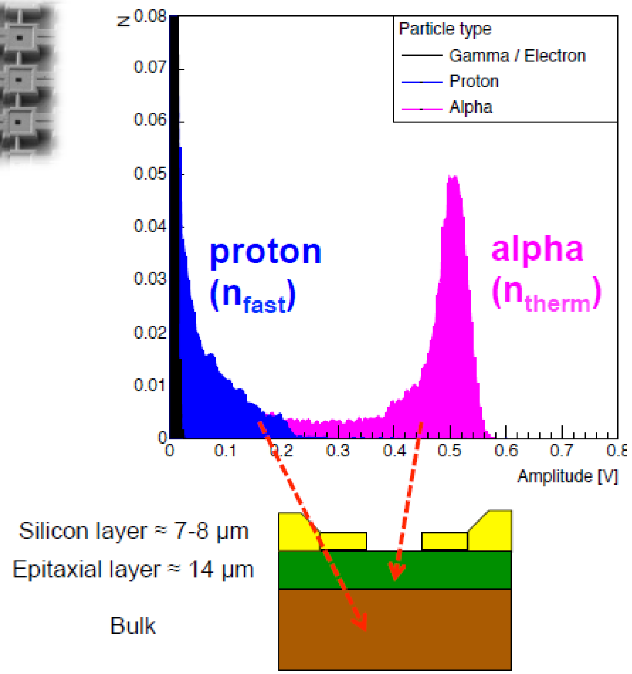
$$TOF = t_{stop} - t_{start} =$$
$$= T_{proton}(\mathbf{r}_v) + T_{PG}(\mathbf{r}_v, \mathbf{r}_d)$$



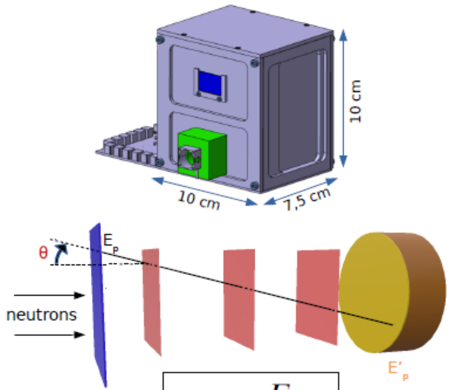
Online control of treatments: neutron detection

- Secondary neutron dose
- Neutron counting (CMOS pixels)
  - Conversion of n_{th} to alpha in ^{10}B layer
- Spectrometry (fast n, 4-50 MeV)
  - Recoil proton tracking with 3 CMOS (FastPIX)



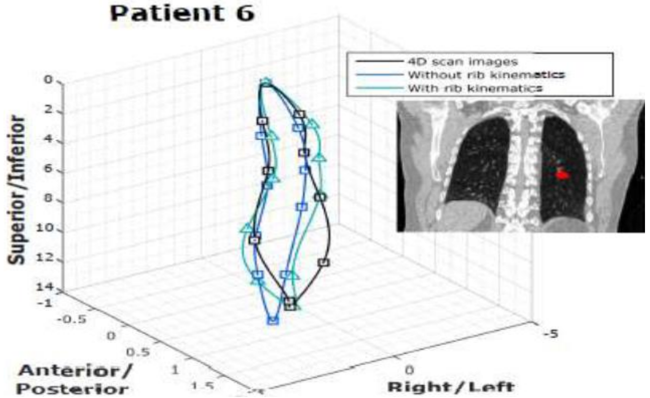


N. Arbor et al, IPHC Strasbourg)



$$E_n = \frac{E_p}{\cos^2\theta}$$

Moving organs



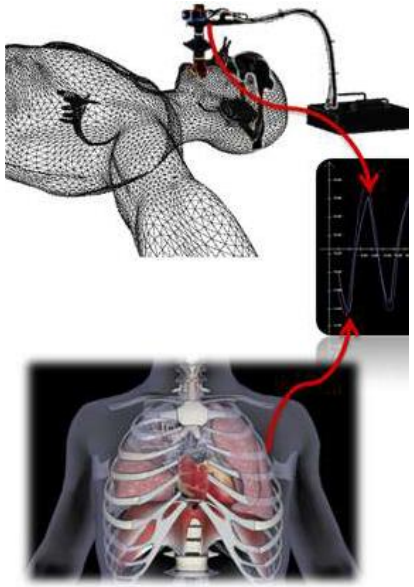
- Biomechanical modelling of organ motion (IN2P3-INS2I)
    - Comparison with 4D CT → need more patient data for training

Future :

- Multiphysics combination with dosimetry and TEP/PG control
- Tracking internal organs from external surrogates
    - Need for pre-clinical validation

  (eg anthropomorphic thorax phantom)

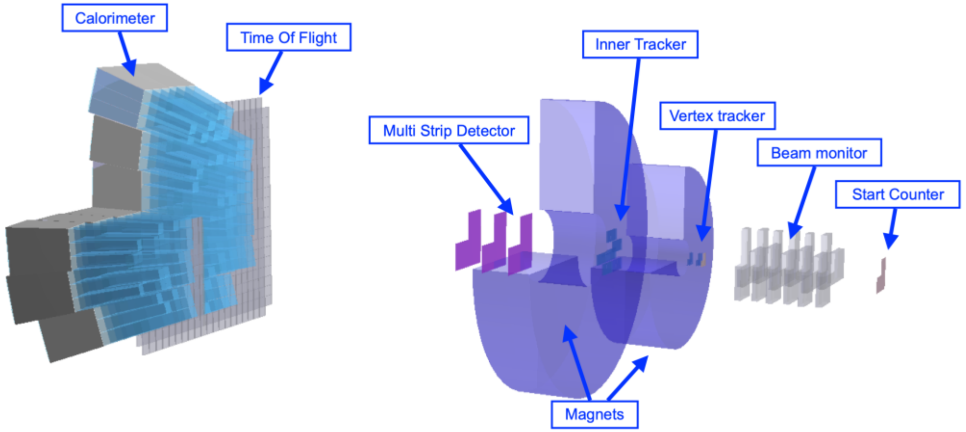
Realistic anthropomorphic phantom
Lung Cancer LuCas (PSI)

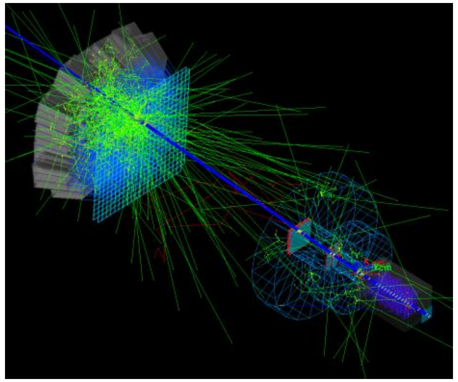


The FOOT collaboration

- FOOT (FragmentatiOn Of Target): measurement of differential cross-sections of p, ^{4}He, ^{12}C, ^{16}O @ 200-700 MeV/n on C, H, O for treatment planning calculation improvement
  - International collaboration: INFN + GSI (Darmstadt) + CNRS-IN2P3 (Strasbourg)
  - Multi-detector setup
  - Several beam tests already performed or planned: @GSI (2019-2021), @CNAO, @HIT (July 2022)

14 publications since 2018





FOOT setup (Geant4)

First experimental charge-changing cross sections (GSI campaign of 2019)

Element	$\sigma_{frag} \pm \Delta_{stat} \pm \Delta_{sys} [mbarn]$	$\Delta_{stat}/\sigma_{frag}$	$\Delta_{sys}/\sigma_{frag}$	$\sigma_{MC} [mbarn]$
He	625 ± 22 ± 21	3.6%	3.6%	621
Li	85 ± 10 ± 5	11.9%	5.6%	67
Be	31 ± 10 ± 3	31.8%	8.8%	33
B	70 ± 10 ± 5	14.9%	7.3%	38
C	113 ± 12 ± 3	10.9%	2.7%	81
N	101 ± 14 ± 5	13.7%	4.8%	105

Courtesy of M. Toppi

Future step: BNCT

- CNAO is presently convening a national research program/consortium
- Possibility to open to external collaborators (2023)
- Possible contributions from France (IN2P3 + INSB)
  - New boron-10 vectors
  - Experimentation protocols (eg in ovo model)
  - Physical/biological dose modelling
  - Neutron field optimization and characterization

Simulation - modelling

- IN2P3 strongly involved in GEANT4-DNA and GATE
- GATE-RTion for light ion pencil-beam scanning
- GATE Biodose actor : includes biophysics models to predict biological efficiency (NanOx, MKM)

→ Inter-comparisons between Geant4-DNA/GATE with other codes used at CNAO would be beneficial : FLUKA, FRoG, UNIVERSE

Conclusion

- Ongoing collaborations
- Fruitful thematical discussions initiated, more to come
- First experiments will take place this year
- CNRS needs to stimulate the research program on hadrontherapy and BNCT

- Motivation for a regular event: common workshop?