

Preliminary results of an in-beam PET prototype for proton therapy

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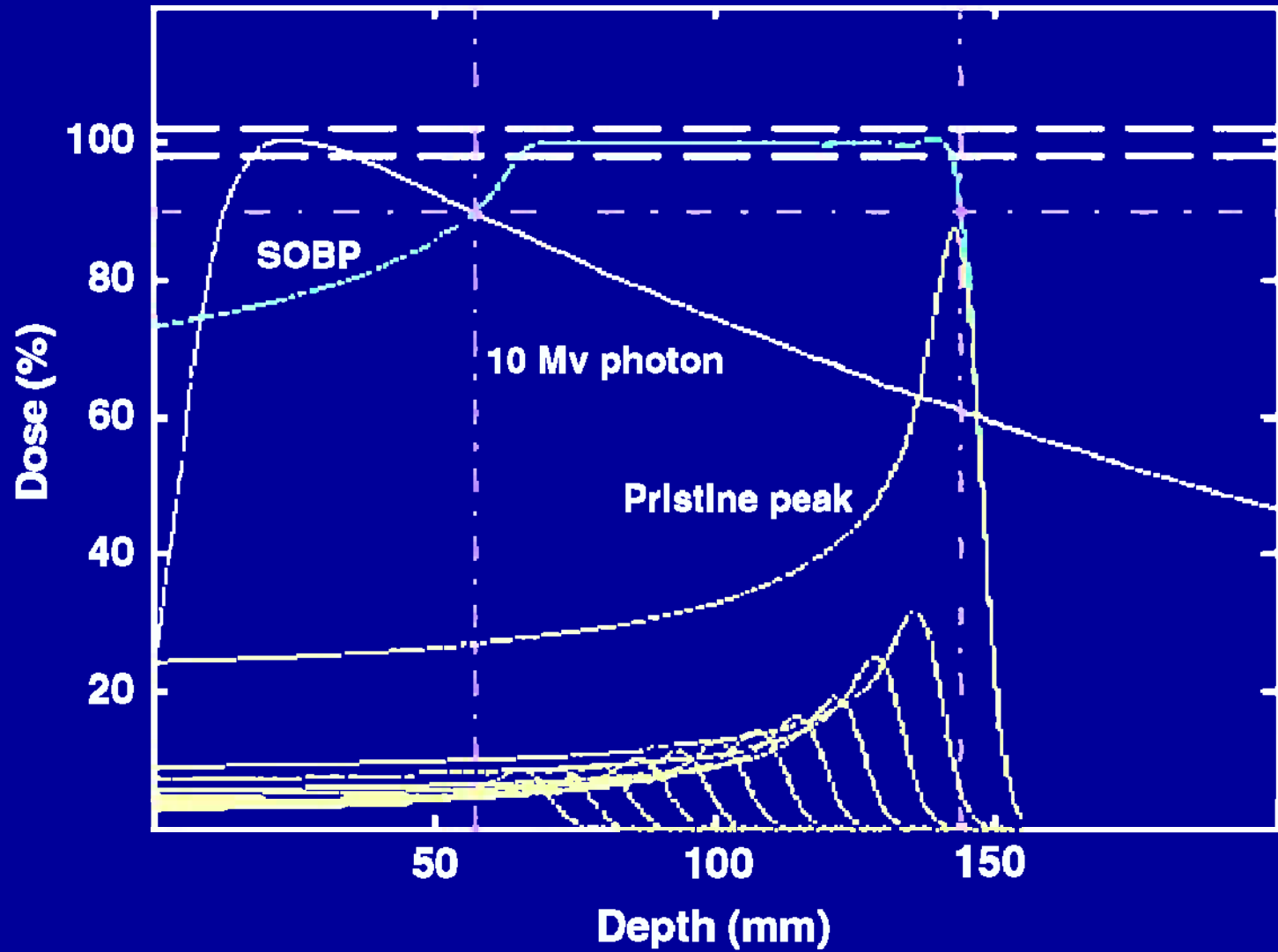
**Friedrich-Alexander-Universität
Erlangen-Nürnberg**



The tumors are still one of the main cause of death reason in Europe, and even if the diagnostic techniques allows the diagnosis of about 60% of all cancers at the stage of a localized primary tumor, the current tumor treatments still fail for 20% of all patients, corresponding to about 300,000 deaths per year in Europe.

The therapeutic effectiveness of conventional X-ray and electron radiation is intrinsically limited by its physical and radiobiological properties. In fact, the dose-depth distribution and the lateral scattering limit the physical selectivity for high precision irradiation of deep-seated tumors.

Heavy charged particles, like protons, can overcome the limitations of conventional electromagnetic radiation due to the more selective energy deposition in depth.



Stringent necessity of monitoring

The higher physical selectivity of ion therapy demands higher precision in the monitoring of the applied treatment due to:

- fractionated therapy
- shifts of the patient
- local tissue reduction

For these reasons in vivo information on the range of ions are desirable, but the complete stopping of the ions in patient prevents the application of electronic portal imaging methods as used in conventional radiotherapy.

Possibilities:

- radiographic imaging of high energy transmitted protons prior to therapeutic irradiation (hadron CT)
- in situ PET

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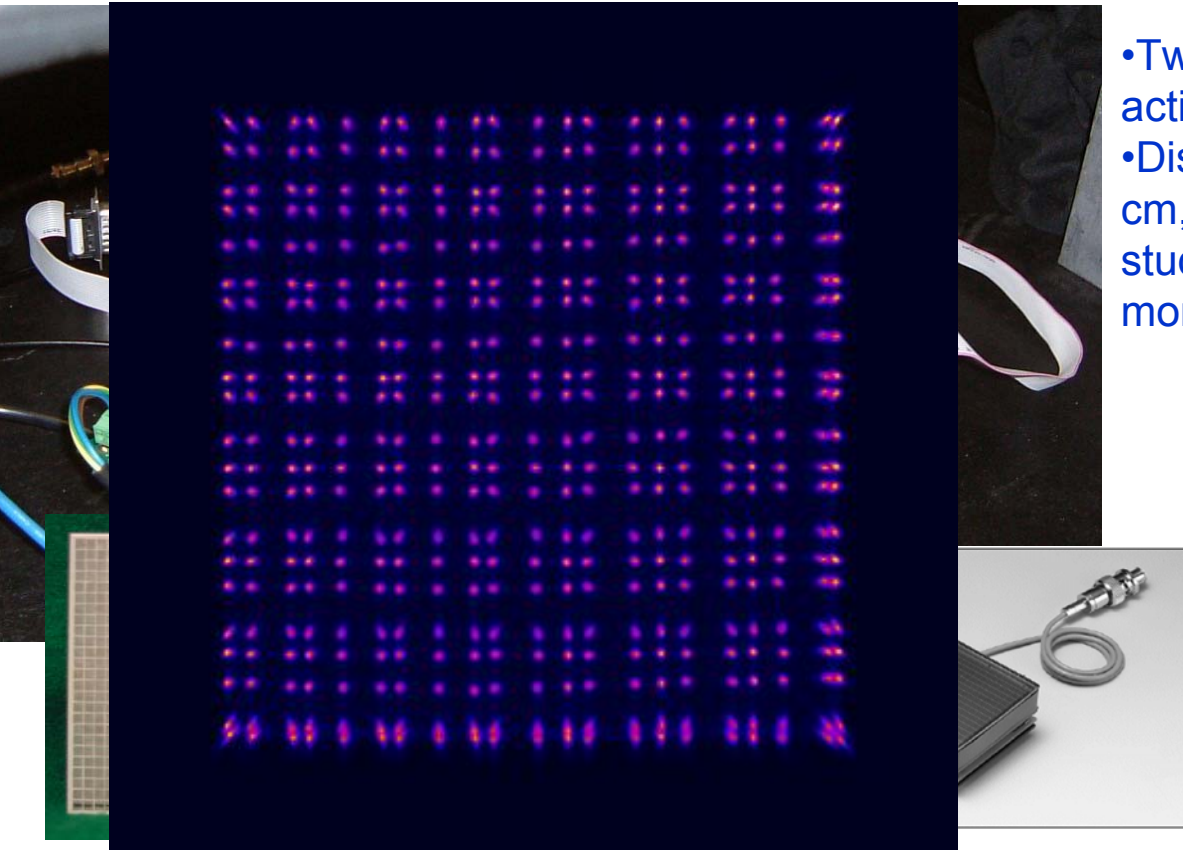
PET-Tomograph prototype

Performances

Conclusions and future work

MPX2 as a proton beam profile meter

The PET-tomograph prototype



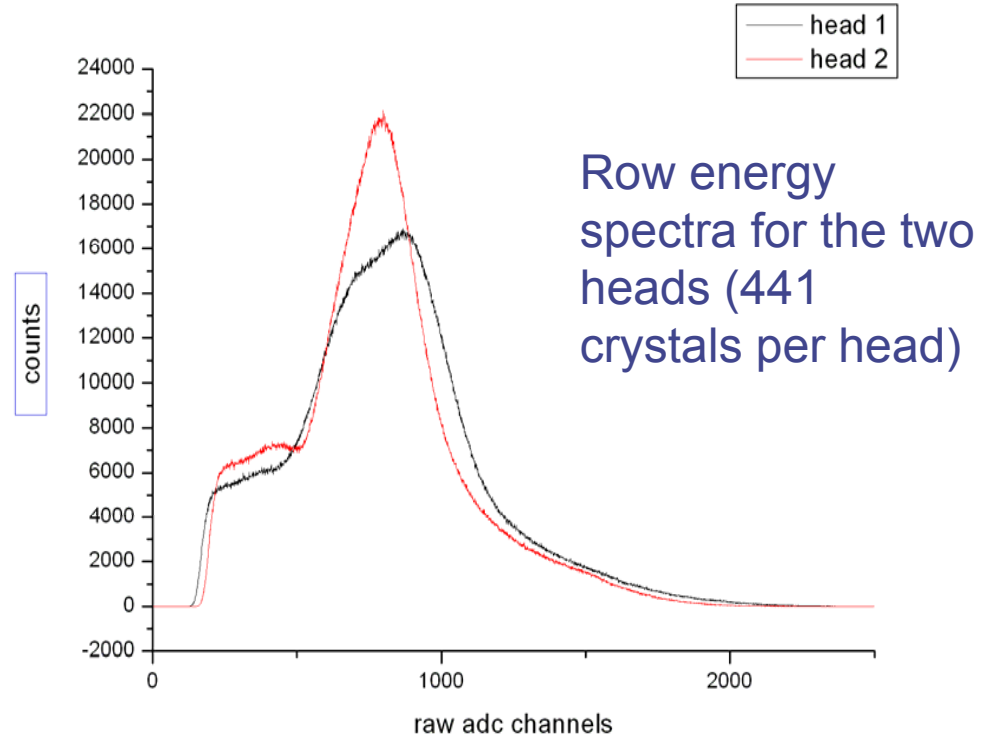
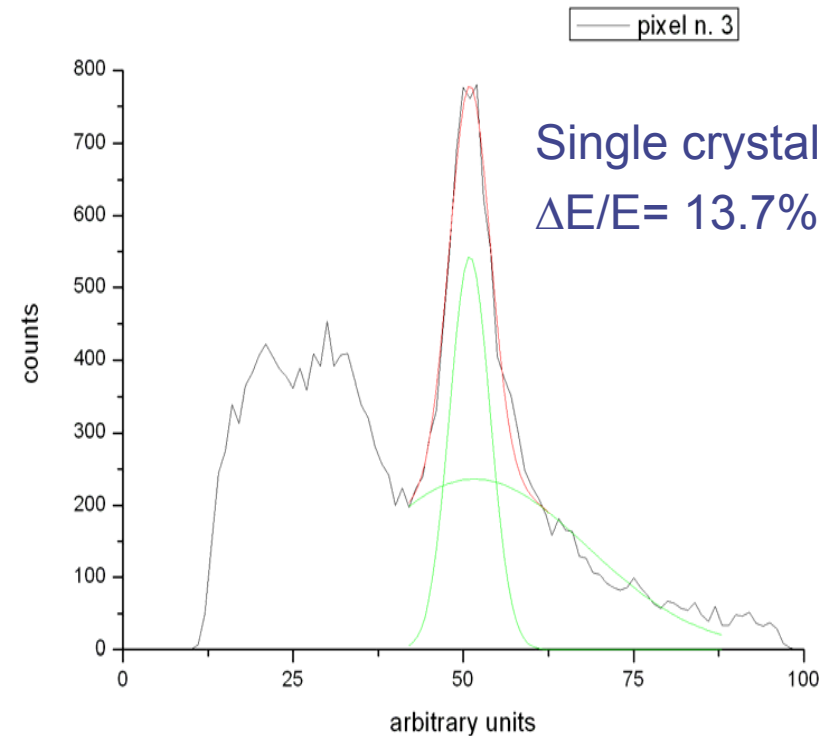
- Two planar heads, each with an active area of 45 mm x 45 mm
- Distance between the heads: 5+5 cm, 7+7 cm, 10+10 cm (for phantoms study) and 5+15 cm (for eye monitoring)



- LYSO crystal matrix, 21 x 21 pixels 2.152 mm x 2.152 mm each (Hilger Crystals)
- Crystal thickness: 18 mm
- 64-anode PMT (Hamamatsu)
- “multiplexed” read-out electronics: 64-inputs/4 outputs

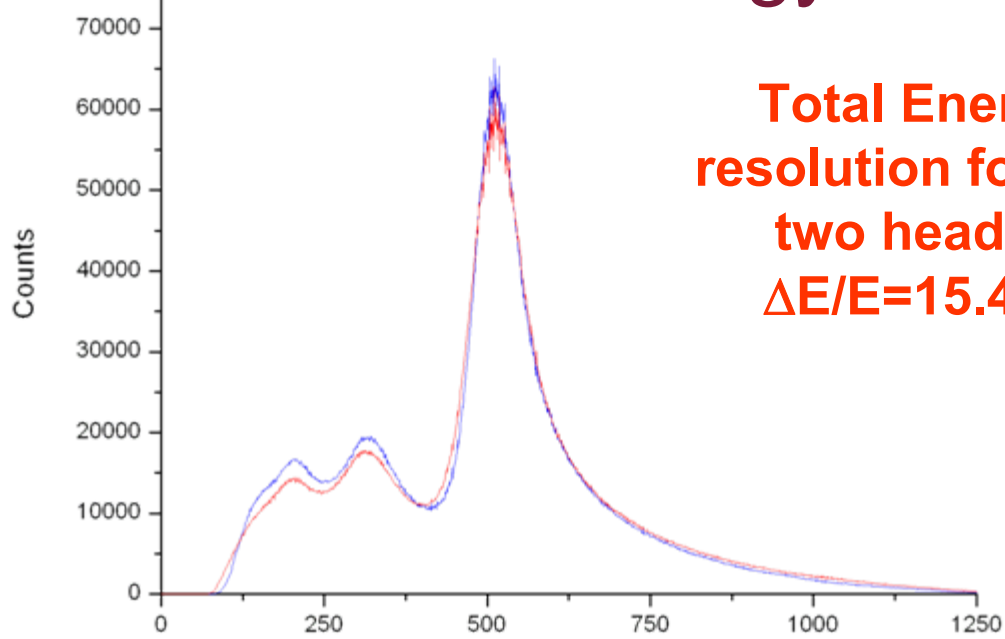
Performances: energy resolution

Using a ^{22}Na source

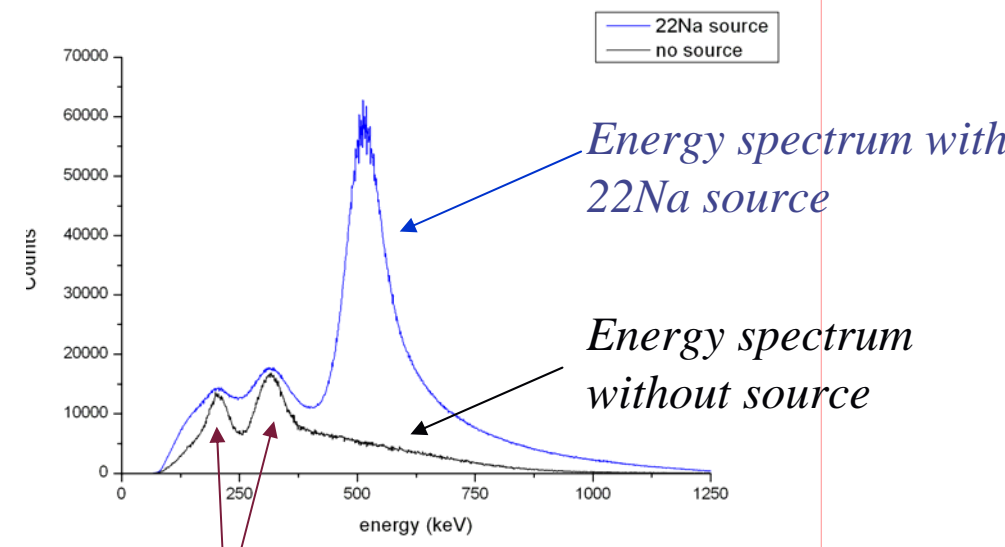


Applying a calibration procedure that corrects the different pixel amplifications

Performances: energy resolution

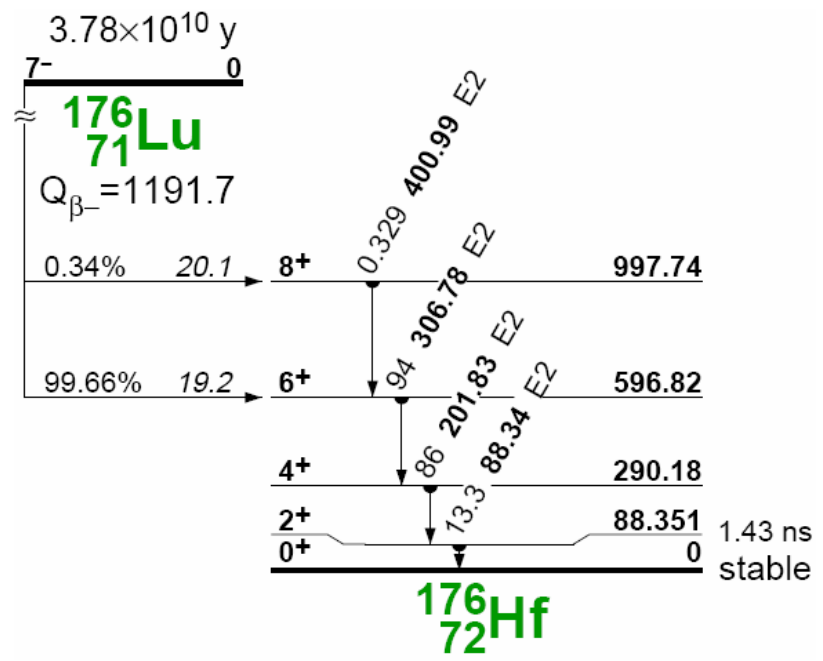


Total Energy resolution for the two heads:
 $\Delta E/E = 15.4\%$



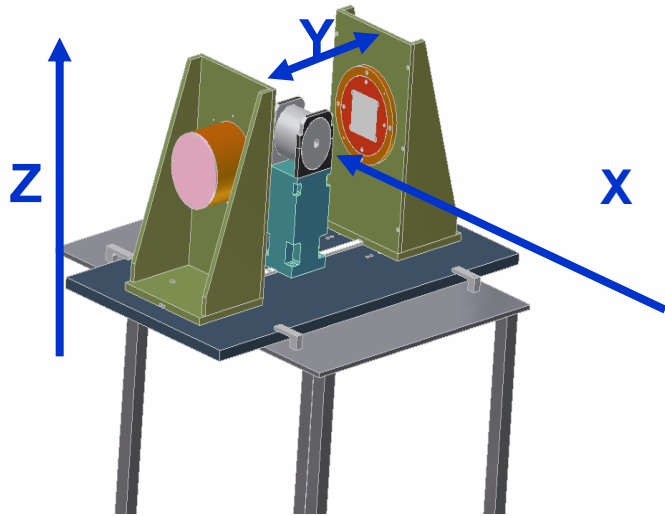
Energy spectrum with ^{22}Na source

Energy spectrum without source



The Lu γ emissions (307 and 202 keV)

Performances: spatial resolution



A ^{22}Na point source was used.
 Reconstructed activity in air: the central slice is shown in the zx and zy planes



		x/z [mm]	y [mm]
AIR	150 keV	1.7	6
	350 keV	1.7	6
PMMA	150 keV	1.9	7
	350 keV	1.9	7

Spatial resolution measured as the FWHM of counts distribution in the central slice of the PET reconstructed image.
 Reconstructed image: 42x42x130 voxels

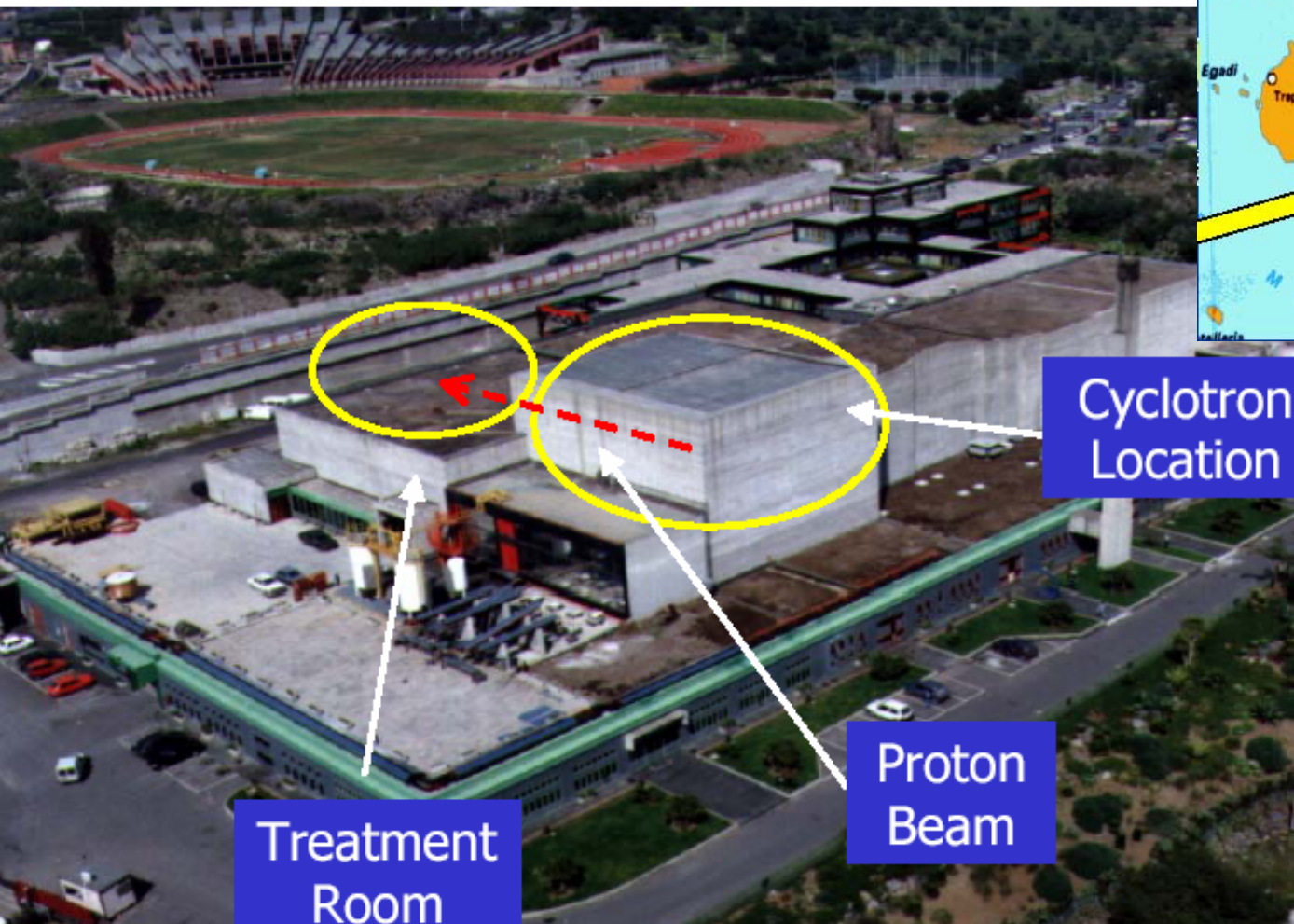
Performances: sensitivity

Using a ^{22}Na point source in air the
Sensitivity = detected-photons/incoming-photons
was measured and simulated with a MC program
SIMSET

Sensitivity	experimental	calculated
$E > 150 \text{ keV}$	1%	1%
$E > 350 \text{ keV}$	0.7%	0.8%

Validation on phantoms @CATANA (Centro di AdroTerapia e Applicazioni Nucleari Avanzate)

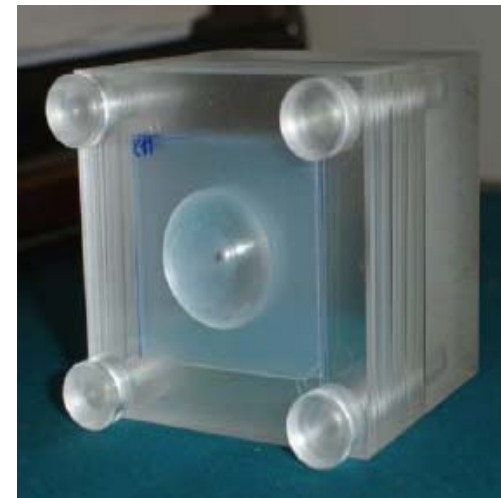
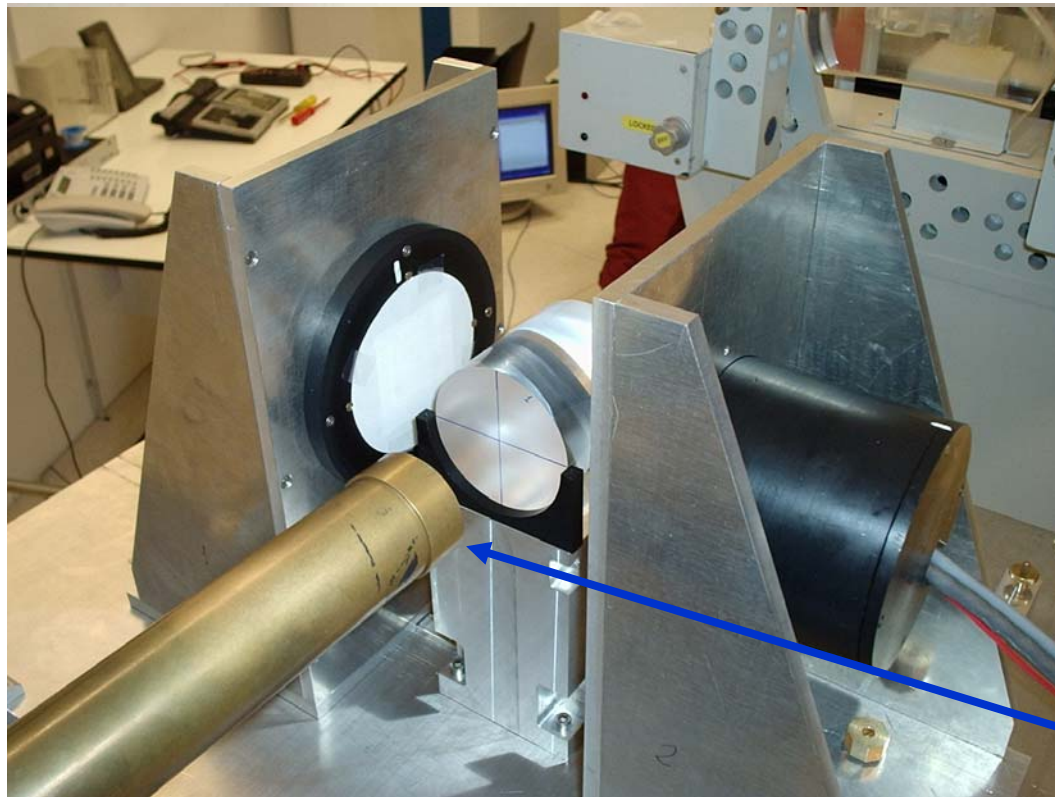
Laboratori Nazionali del Sud –INFN Catania, Italy



LNS Superconducting Cyclotron is used for the treatment of the choroidal and iris melanoma (in Italy about 300 new cases for year) with 62 MeV proton η_2

Validation on phantoms @ CATANA

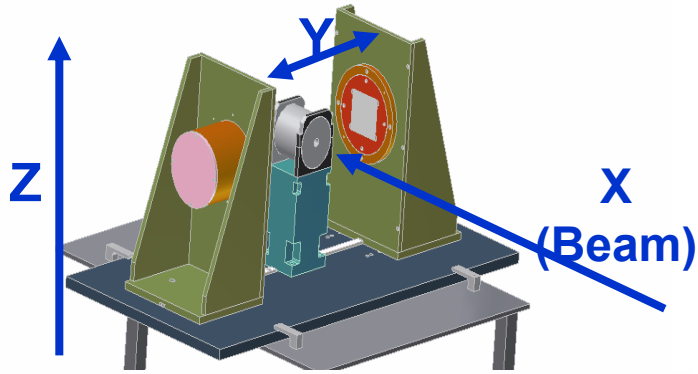
The CATANA beam line (INFN-LNS, Catania, Sicily) provides 62 MeV protons for ocular melanoma therapy



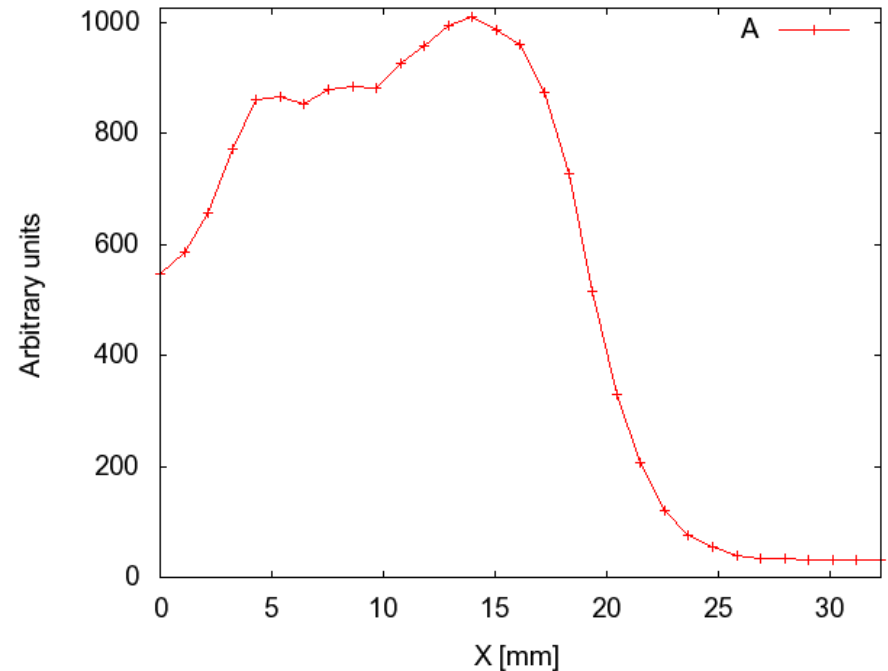
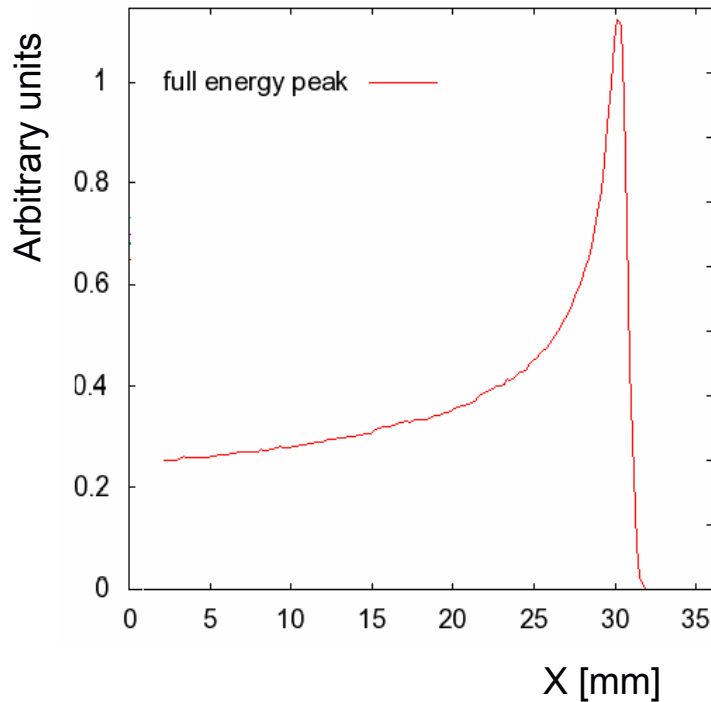
Nominal energy: 62 MeV
Energy spread: 200-300 keV
Final collimator: max 25 mm \varnothing
Proton flux: $\sim 10^7$ p/s

The last part of the 62 MeV proton beam line collimator is well visible on the left.

Proton beam



The proton beam impinged on a cylindrical PMMA phantom (7 cm long and 7cm in diameter) and then 3 different range shifters were added



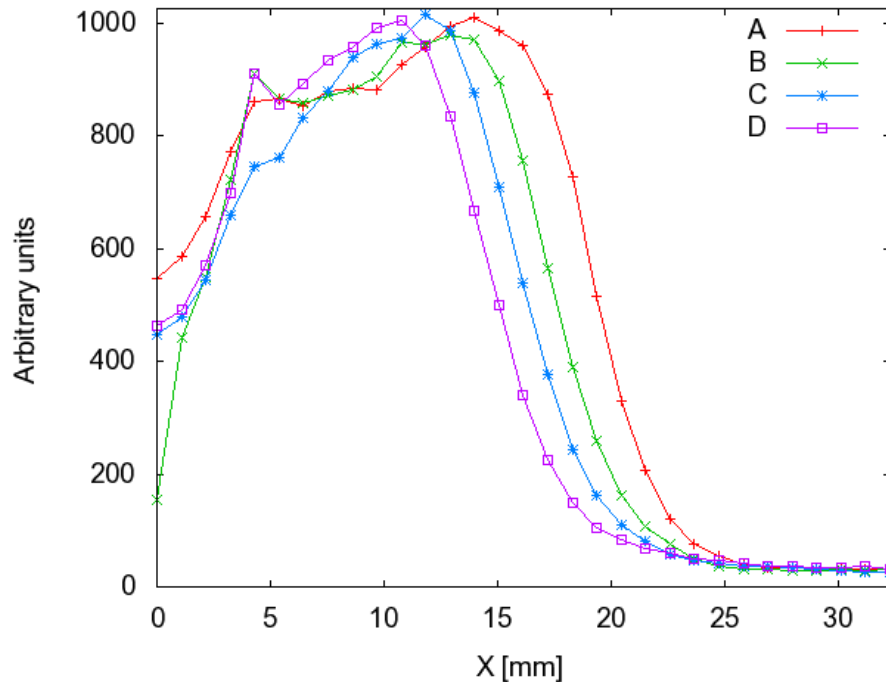
Longitudinal *dose* profiles
measured with a Marcus camera
E= 62.5 MeV D=40 Gy

Longitudinal activity reconstructed
profiles
E= 62.5 MeV D=40 Gy

Activity profiles

- A:** no range shifter
- B:** 2 mm PMMA
- C:** 3.58 mm PMMA
- D:** 5.4 mm PMMA

90 sec irradiation time: $D < 40$ Gy
Acquisition time: 30 min
Full energy: $E = 62.5$ MeV
Distance between heads: 14 cm



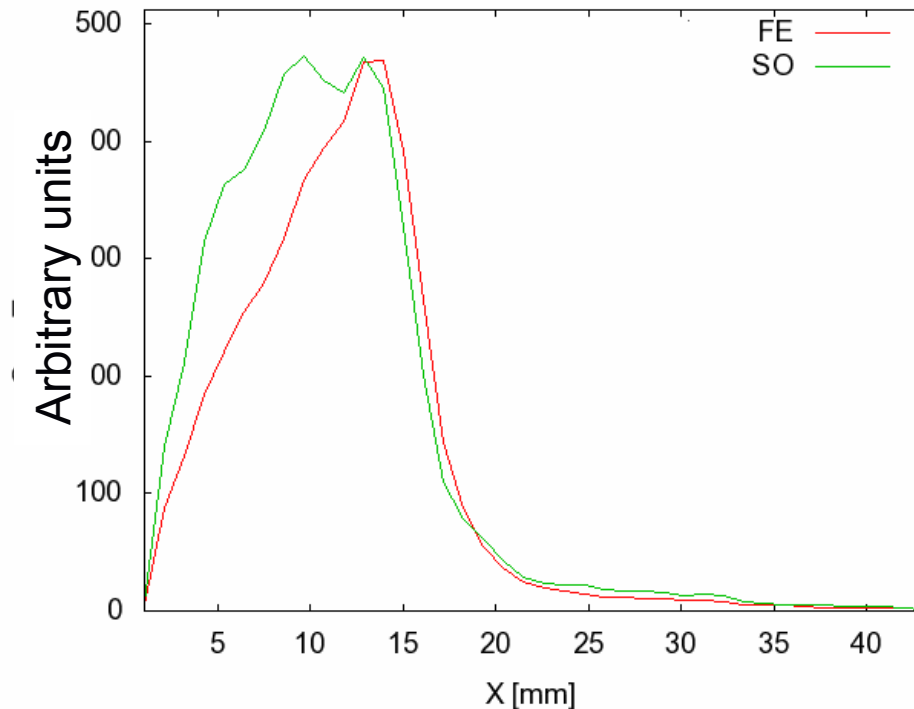
Range shifter difference (mm PMMA)	Reconstructed difference (mm PMMA)
2	1.9
1.58	1.4
1.82	1.4

Longitudinal profiles (XZ) on the 3 central slices of the PET reconstructed image from induced activity.

Full Energy and Spread Out peaks

FE: $E = 62.5$ MeV

SOBP: 12 mm, $E_{\max} = 62.5$ meV

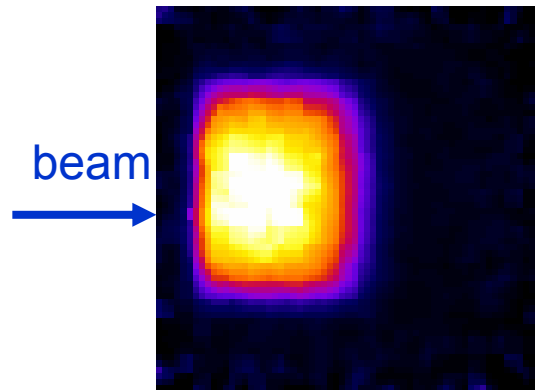


Induced activity longitudinal profiles (XZ) on the central slice of the PET reconstructed image

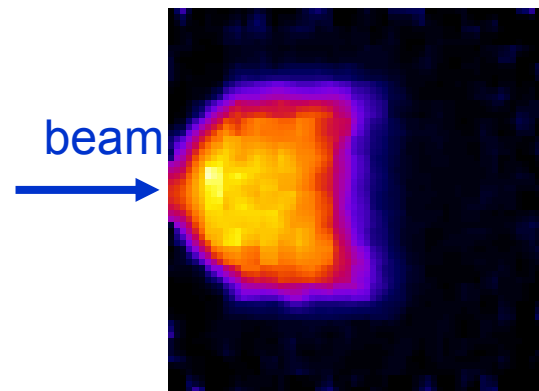
Cylindrical vs. eye PMMA phantom

- 12mm SOBP on PMMA, 2mm eye tissue Range Shifter, 25mm \varnothing final collimator
- 15 Gy delivered in about 60 s
- 15 minutes acquisition
- 350-850 keV energy window

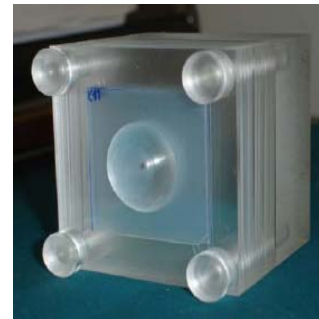
Central slice of the reconstructed images (xz plane)



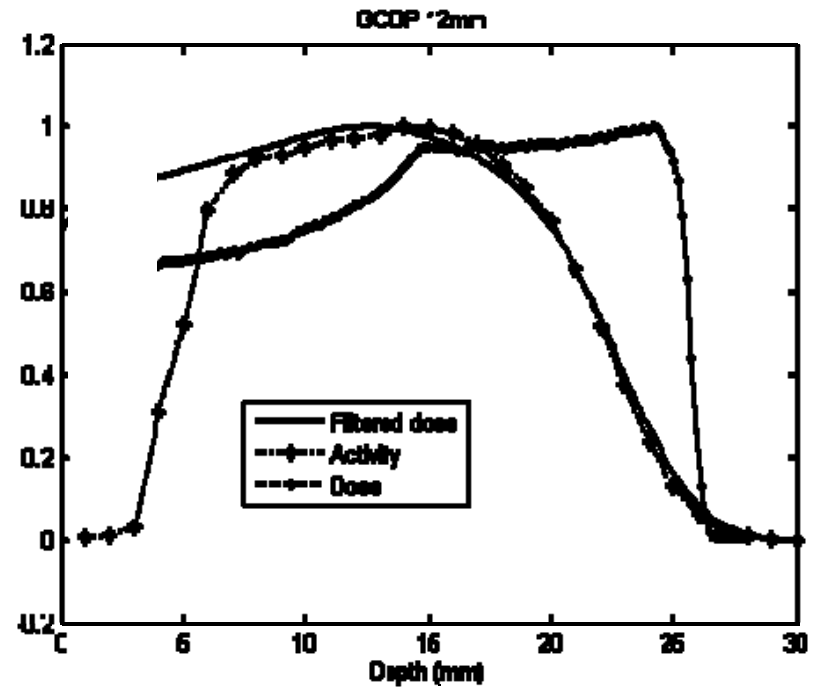
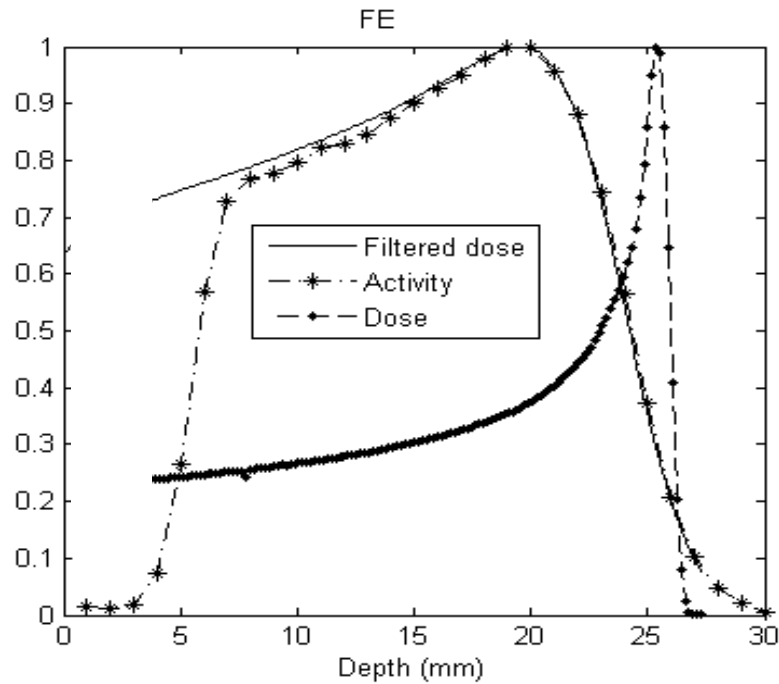
flat entrance surface



spherical entrance surface



Unfolding: very preliminary results



Filter extrapolated from the data available for the Full Energy Bragg peak and measured activity

Filtered dose: β^+ activity distribution obtained from the application of the filter function to measured dose depth profiles

Conclusions and future work

We realized and started to characterize an in-beam PET prototype for proton therapy

The spatial resolution in the coronal direction is regulated by the crystal dimension

We were able to measure range shifter differences down to 2 mm

We are working on:

- Improve the filtering approach for proton and carbon range extrapolation
- Improve the covered solid angle (from $5 \times 5 \text{ cm}^2$ to $10 \times 10 \text{ cm}^2$)