Development of a camera for imaging of prompt gamma rays in measurements of proton beam range

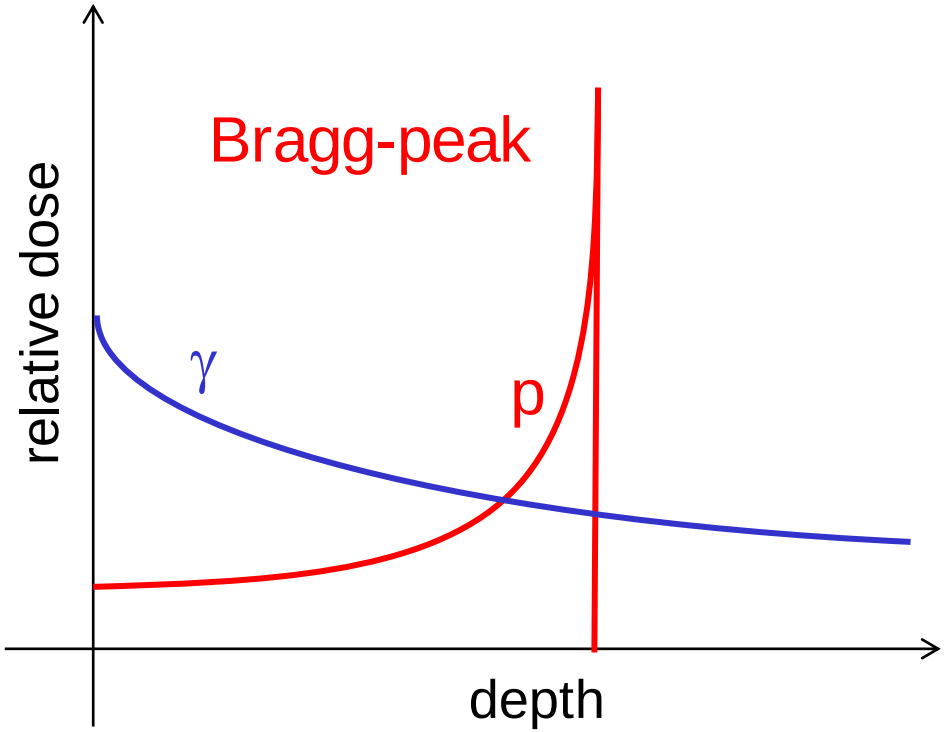
P.Busca[1,2], C.Fiorini[1,2], R.Peloso[1,2], M.Basilavecchia[3], T.Frizzi[3], D. Prieels[4], J. Smeets[5*], F. Stichelbaut[4], A. Benilov[4], F. Roellinghoff[4]

[1]*Politecnico di Milano and INFN, Milano, Italy*
[2]*XGLab, Milano, Italy*
[4] *Ion Beam Applications S.A., Louvain-la-Neuve, Belgium*
[5] *Department of Nuclear Metrology, Université Libre de Bruxelles, Brussels, Belgium*

• Work supported in part by the European Union Seventh Framework Program (FP7/2007-2013) under grant agreements nos. 241851 (ENVISION) and 264552 (ENTERVISION).
• HICAM gamma detector developed within the EC contract n.LSHC-CT-2006-037737.
• *supported by the Belgian FNRS (aspirant)

carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Proton therapy



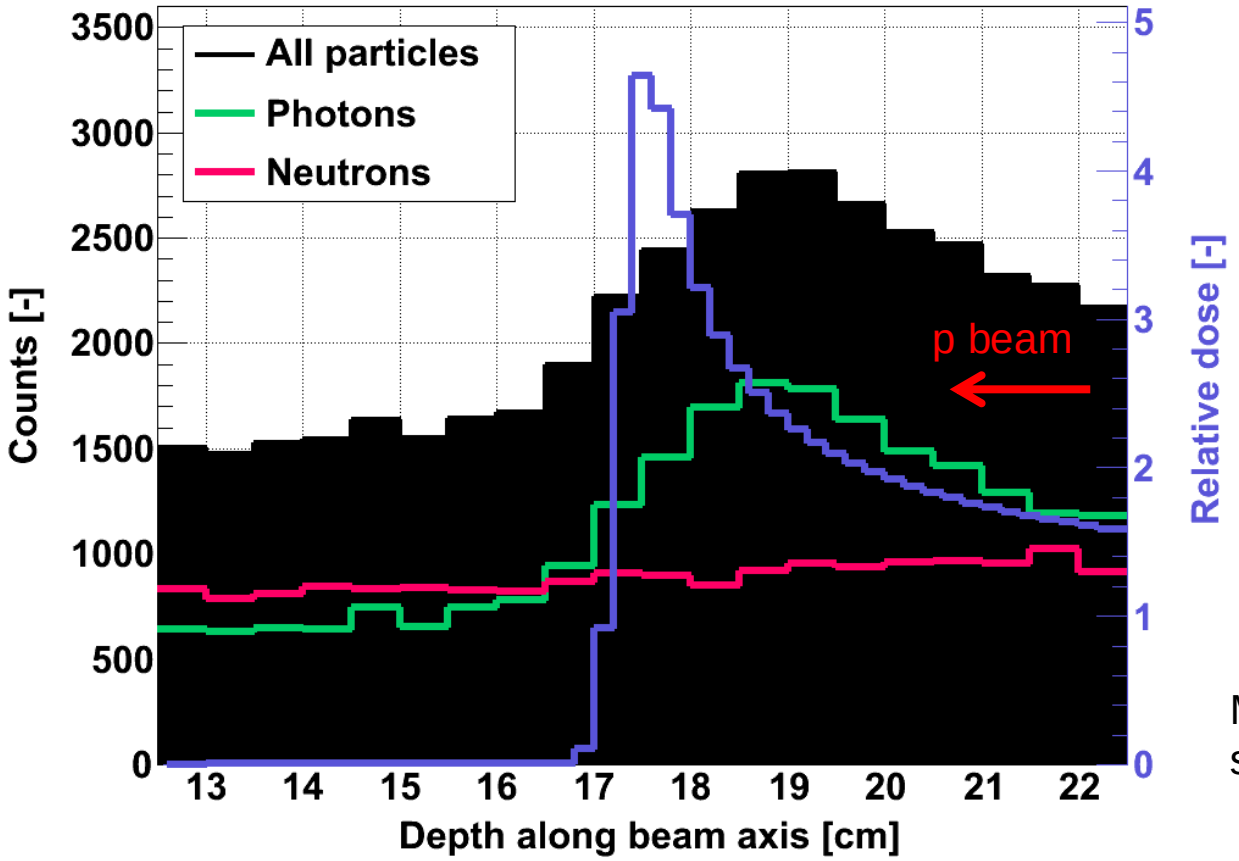
• particle (proton) therapy has a growing role in cancer treatment.
• possibility to release the maximum of the dose in the target site, limiting the dose to normal tissue

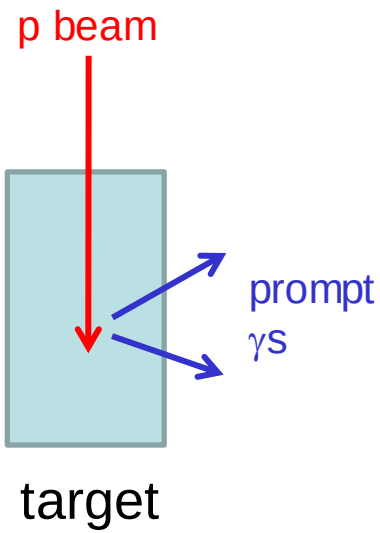
• the measurement of the proton beam range in the target is very important: real range of proton beams in patients may contain uncertainties of up to 10-15 mm (uncertainties on tissue composition, density, organ motions, patient positioning, etc).

carlo.fiorini@polimi.it
Politecnico di Milano, Italy

One method to measure proton beam range is based on the measurement of prompt gamma rays (energies up to 10MeV) emitted by excited nuclei during proton irradiation.

(F. Stichelbaut, Y. Jongen, 39th Meet. of the Particle Therapy Co-Operative Group, San Francisco, October 2003)

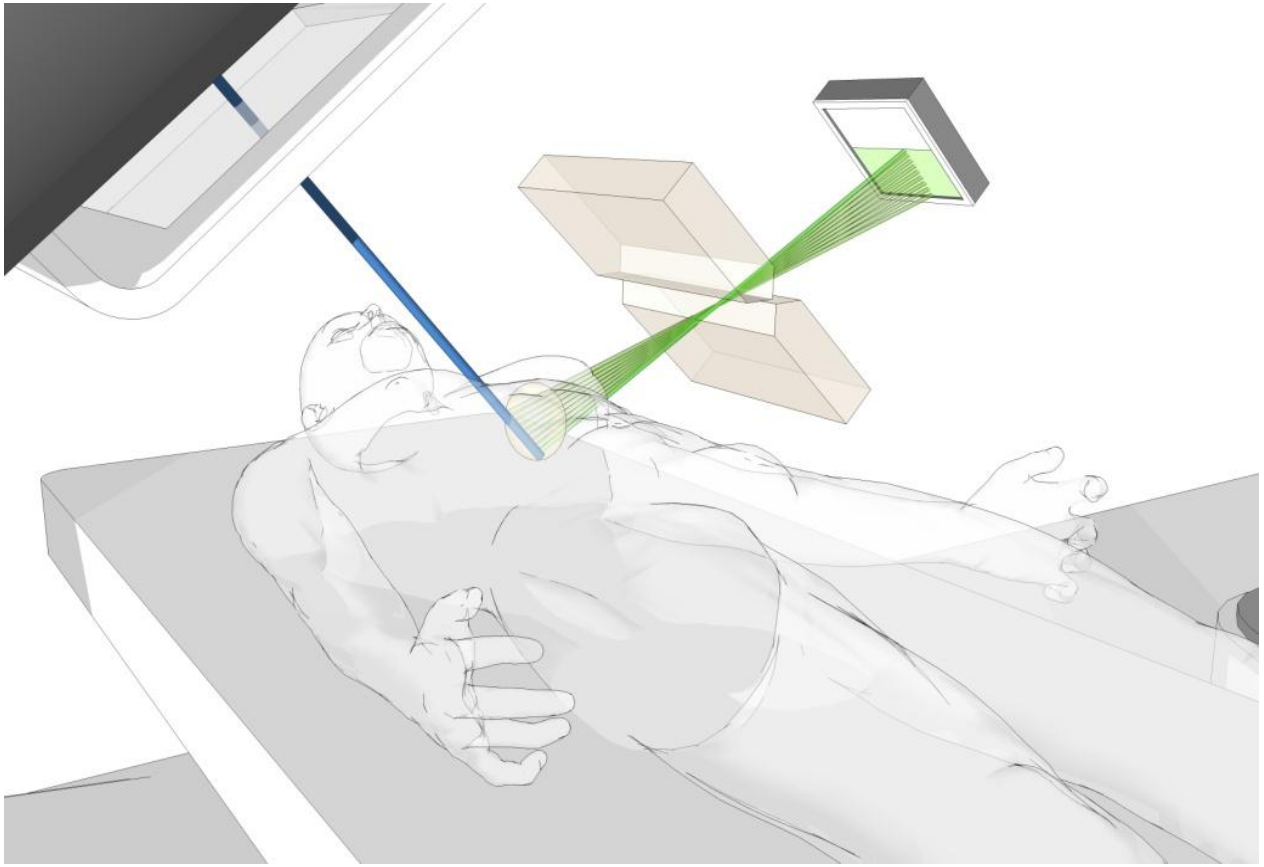




Monte Carlo simulation

carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Practical concept of a prompt gamma camera which allows checking in real-time the range of a single pencil beam with a 'mm' accuracy

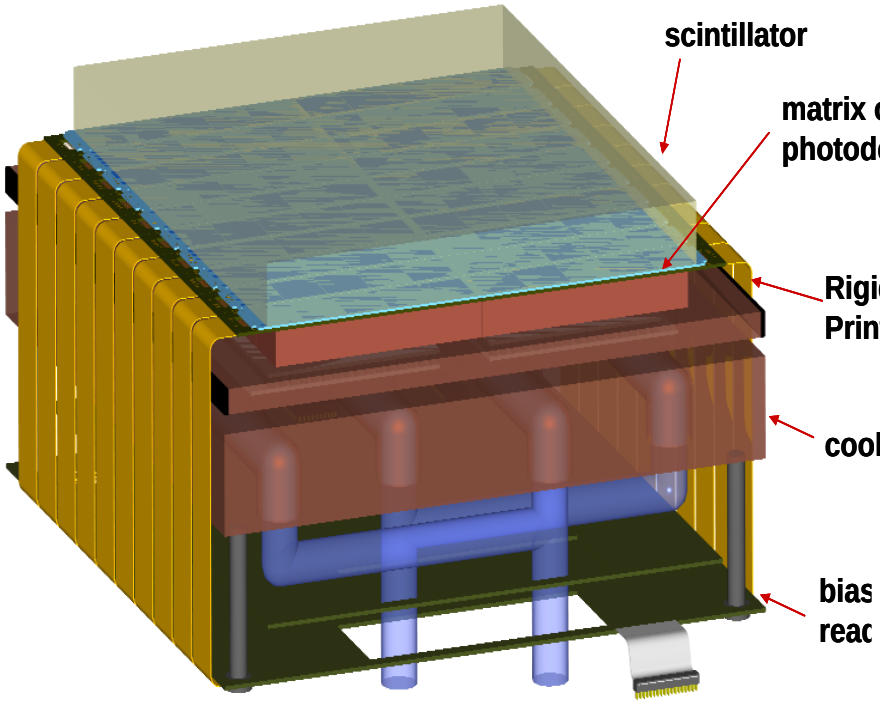


(D. Prieels, J. Smeets, F. Stichelbaut, A. Benilov, J.C. Dehaes, A. Dubus, F. Roellinghoff, 50th Meet. of the Particle Therapy Co-Operative Group (Philadelphia), May 2011

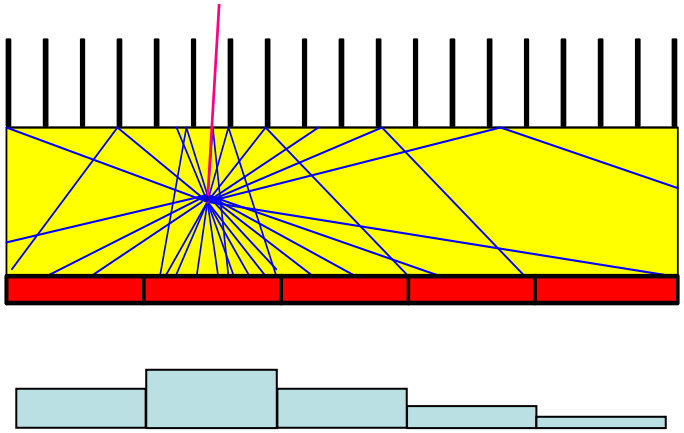
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

HICAM:HIgh resolution gamma CAMera

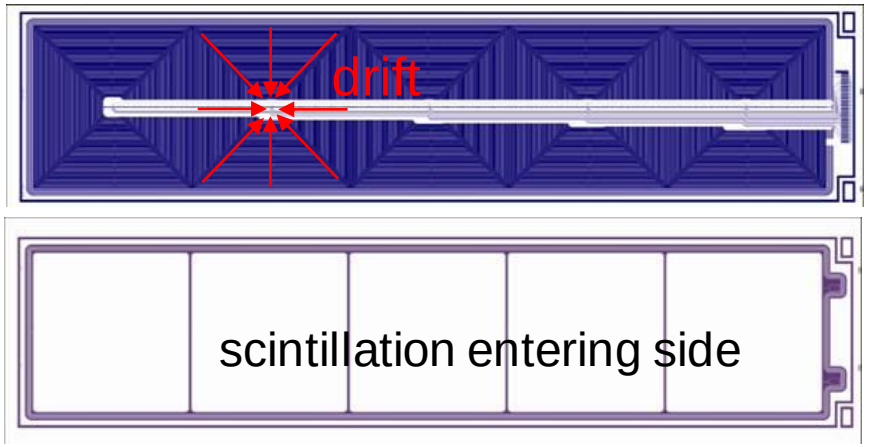
Research project from European Community
(www.hi-cam.org)



Anger camera principle



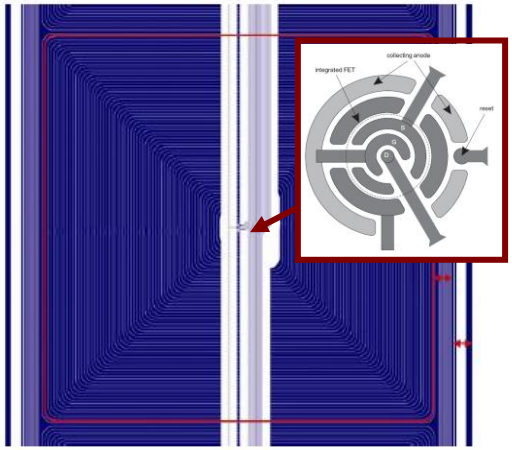
Silicon Drift Detectors

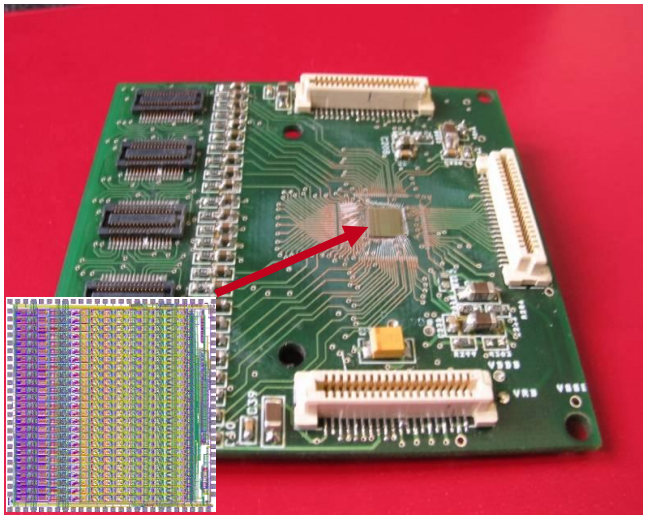


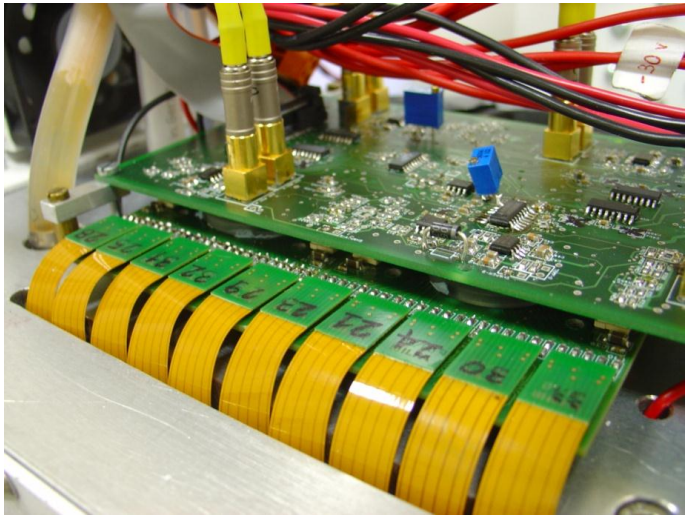
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

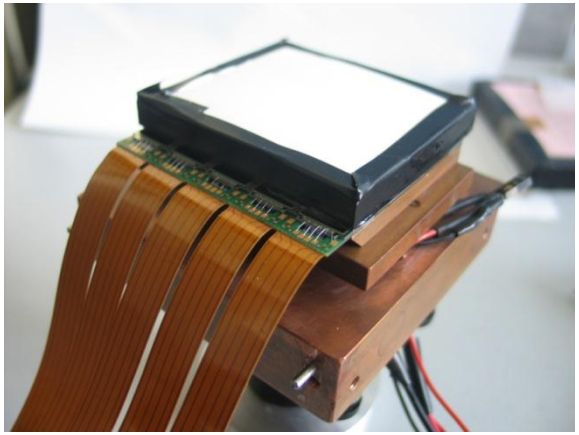
The HICAM gamma camera development

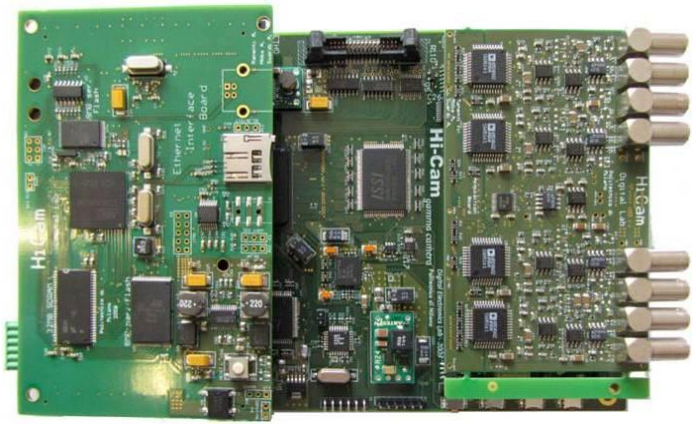
(R.Peloso, et al., “The HICAM Gamma Camera”, Nuclear Science Symposium Conference Record (NSS/MIC), 2010 IEEE)

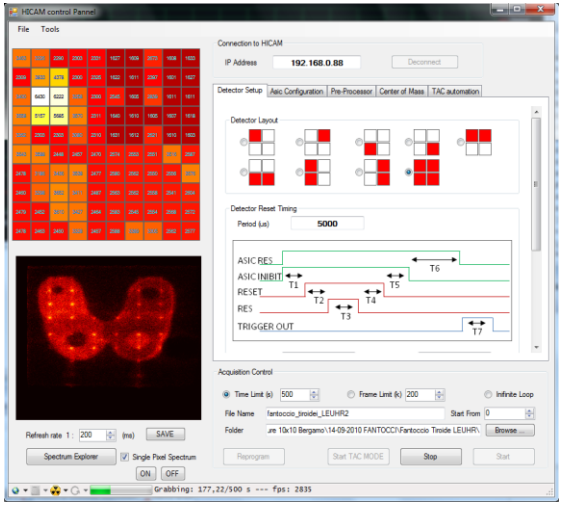






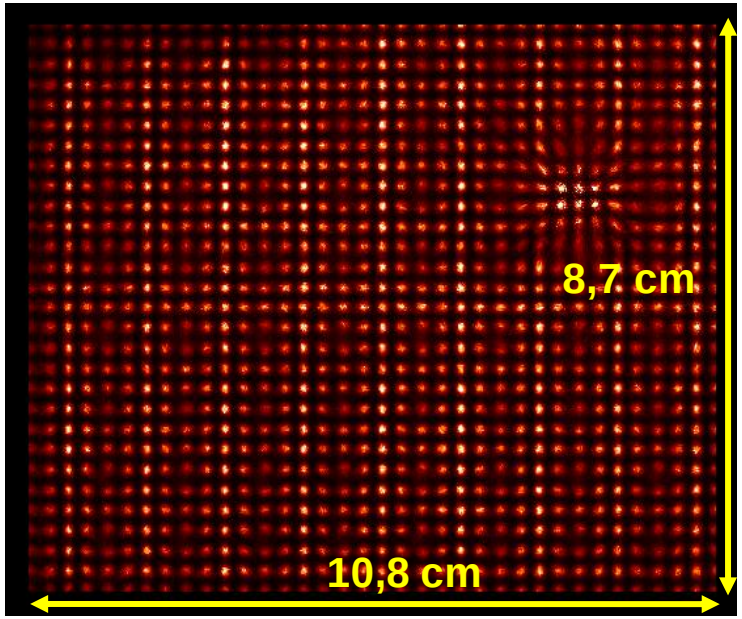




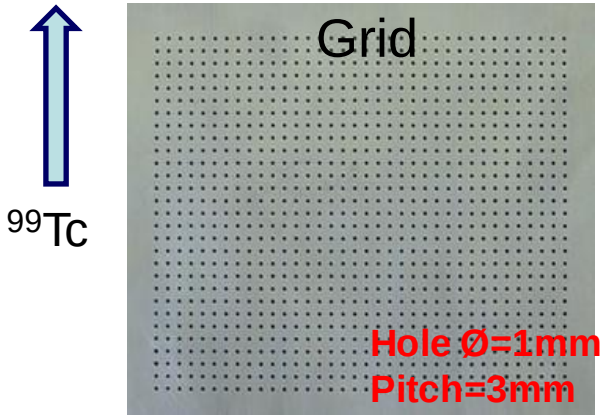


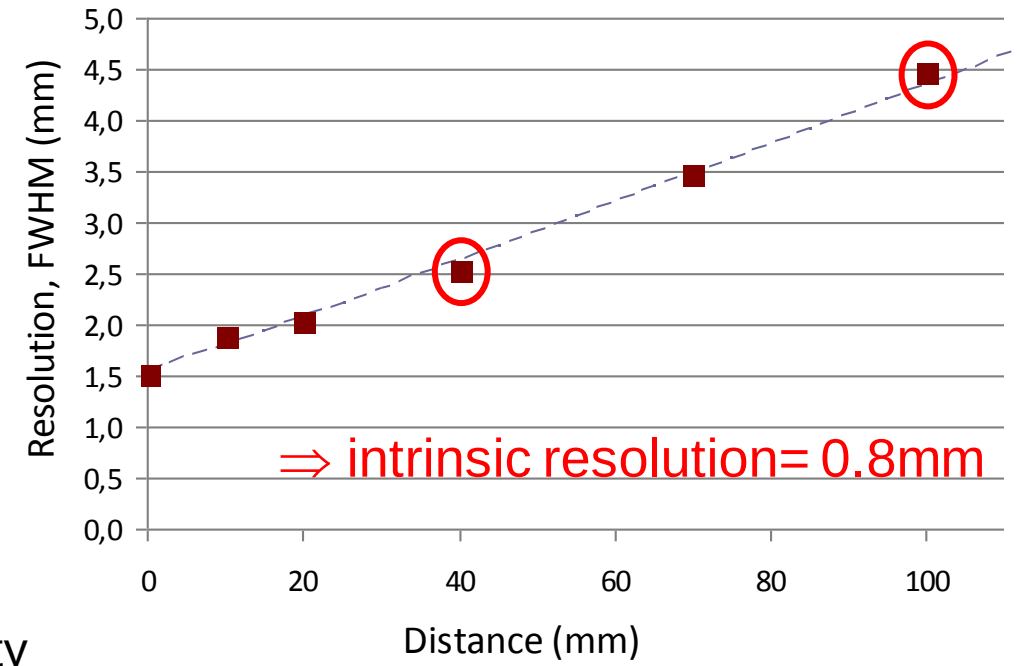
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Imaging performances with ^{99}Tc (140keV)



corrected for linearity and uniformity



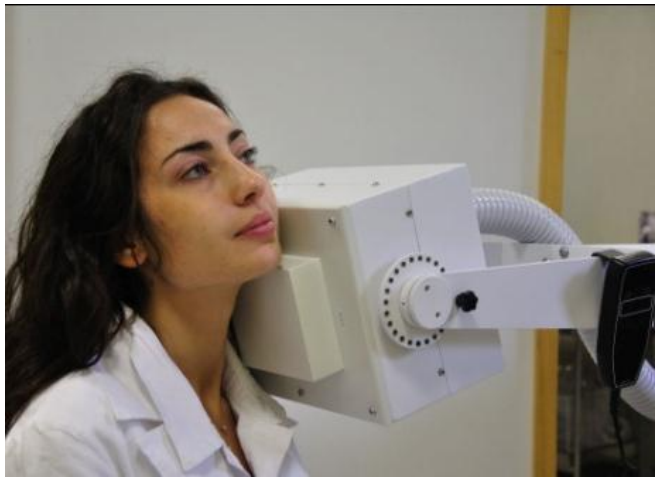


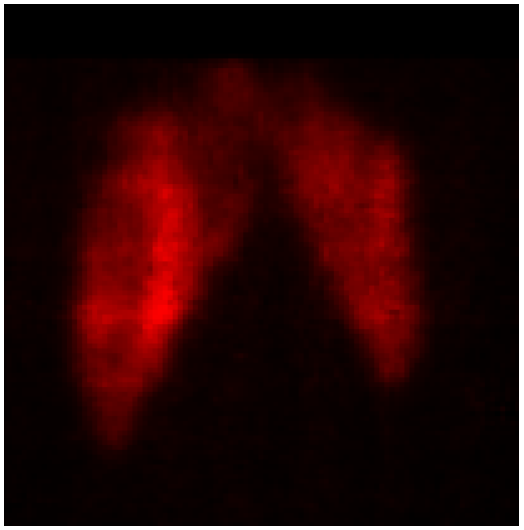
LEUHR parallel hole collimator

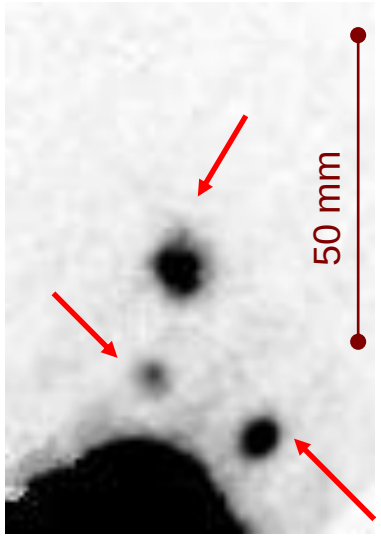
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

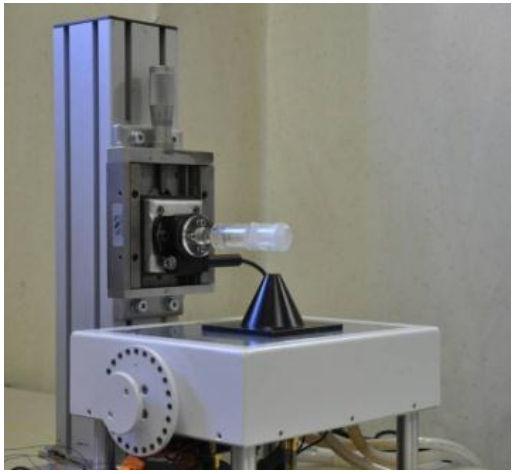
Applications of the HICAM gamma camera

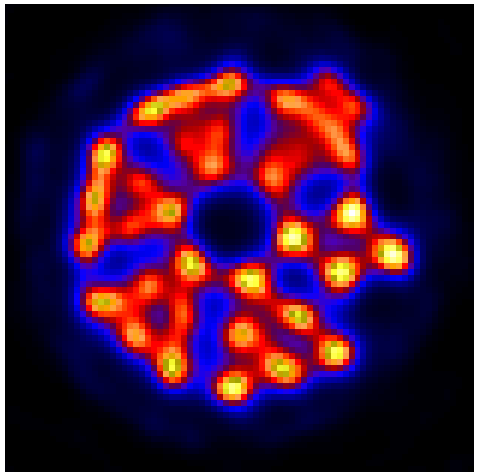
(P.Busca, et al., "Applications of the HICAM Gamma Camera", Nuclear Science Symposium Conference Record (NSS/MIC), 2010 IEEE)

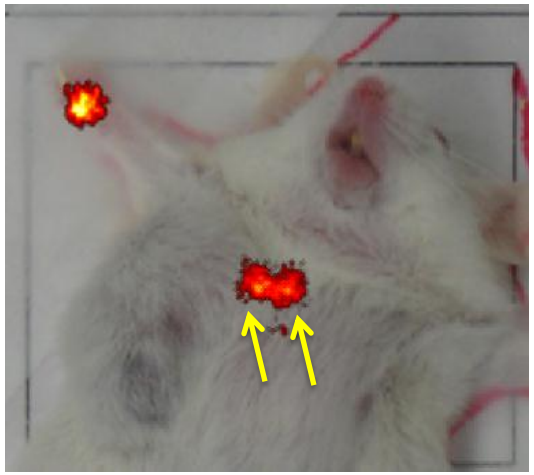






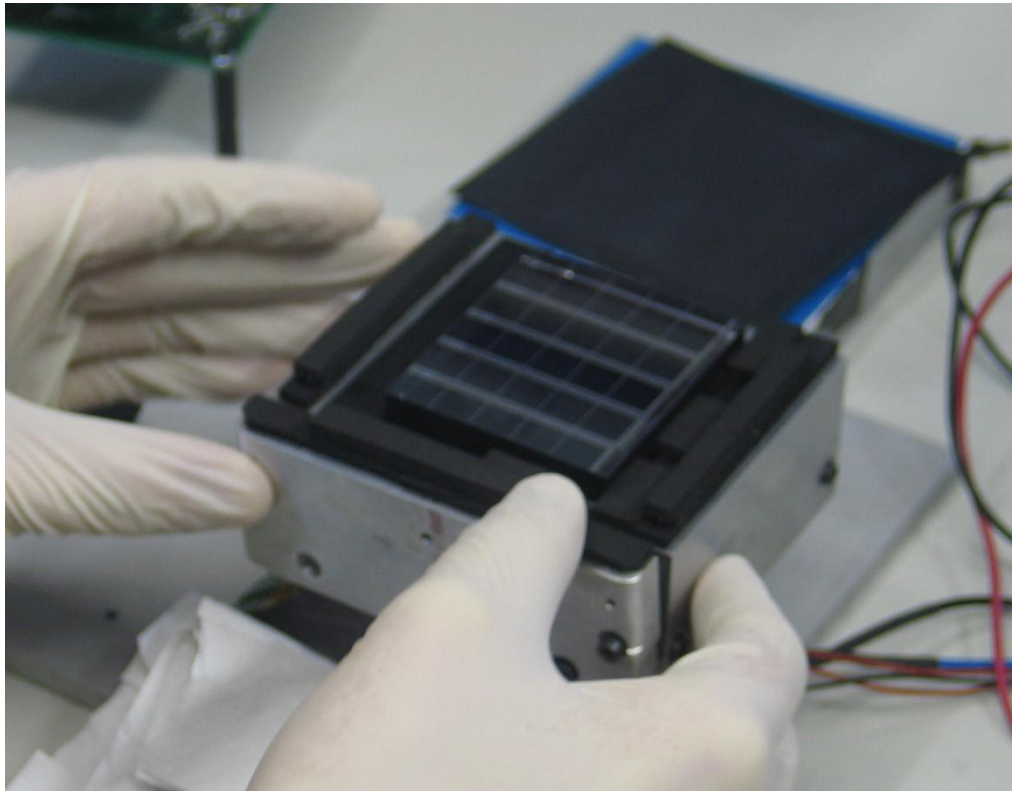






carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Modification of the 5x6cm^2 HICAM gamma camera for high-energy (1-10MeV) imaging

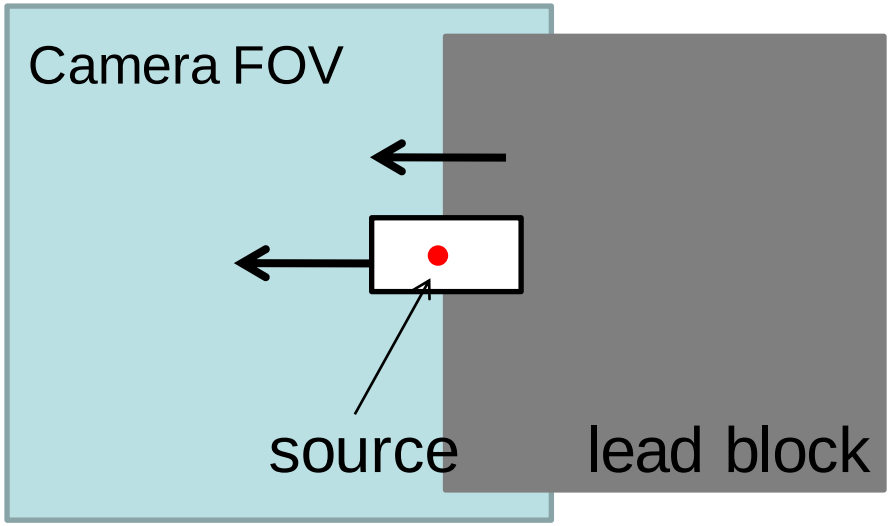


- 1cm thick LYSO scintillator (η~37%@1MeV, ~22%@5MeV)
- light collection purposely limited (i.e. all absorbing surfaces) to match readout ASIC dynamic range (designed for 200keV) ($\Rightarrow$ ~ 5e-/keV, vs. 30ph./keV from LYSO)

carlo.fiorini@polimi.it
Politecnico di Milano, Italy

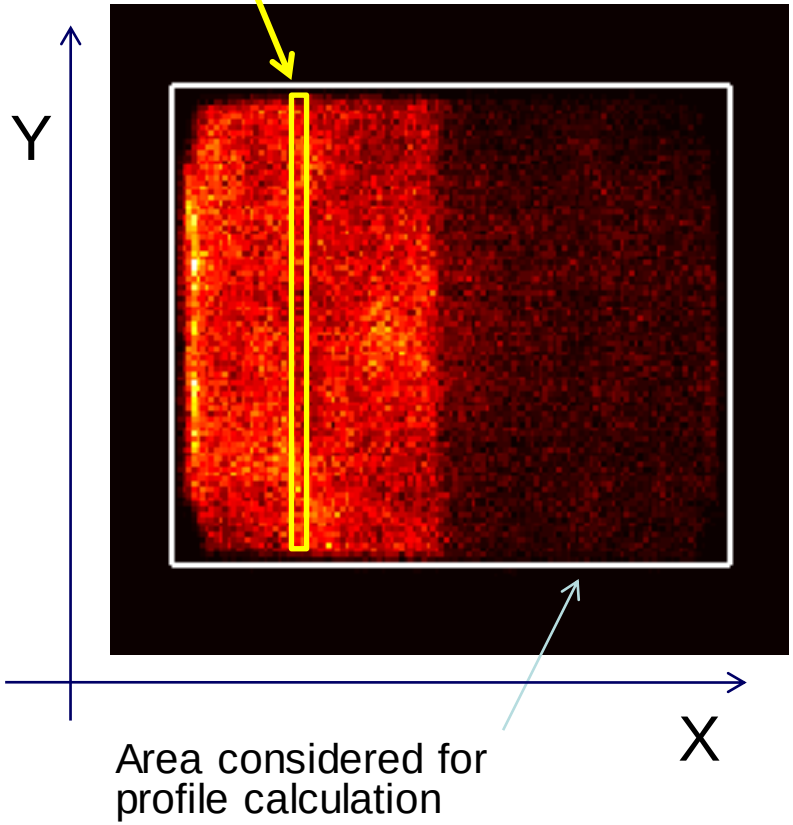
Laboratory characterization of the camera

Source: ^{60}Co (1.17MeV, 1.33MeV)

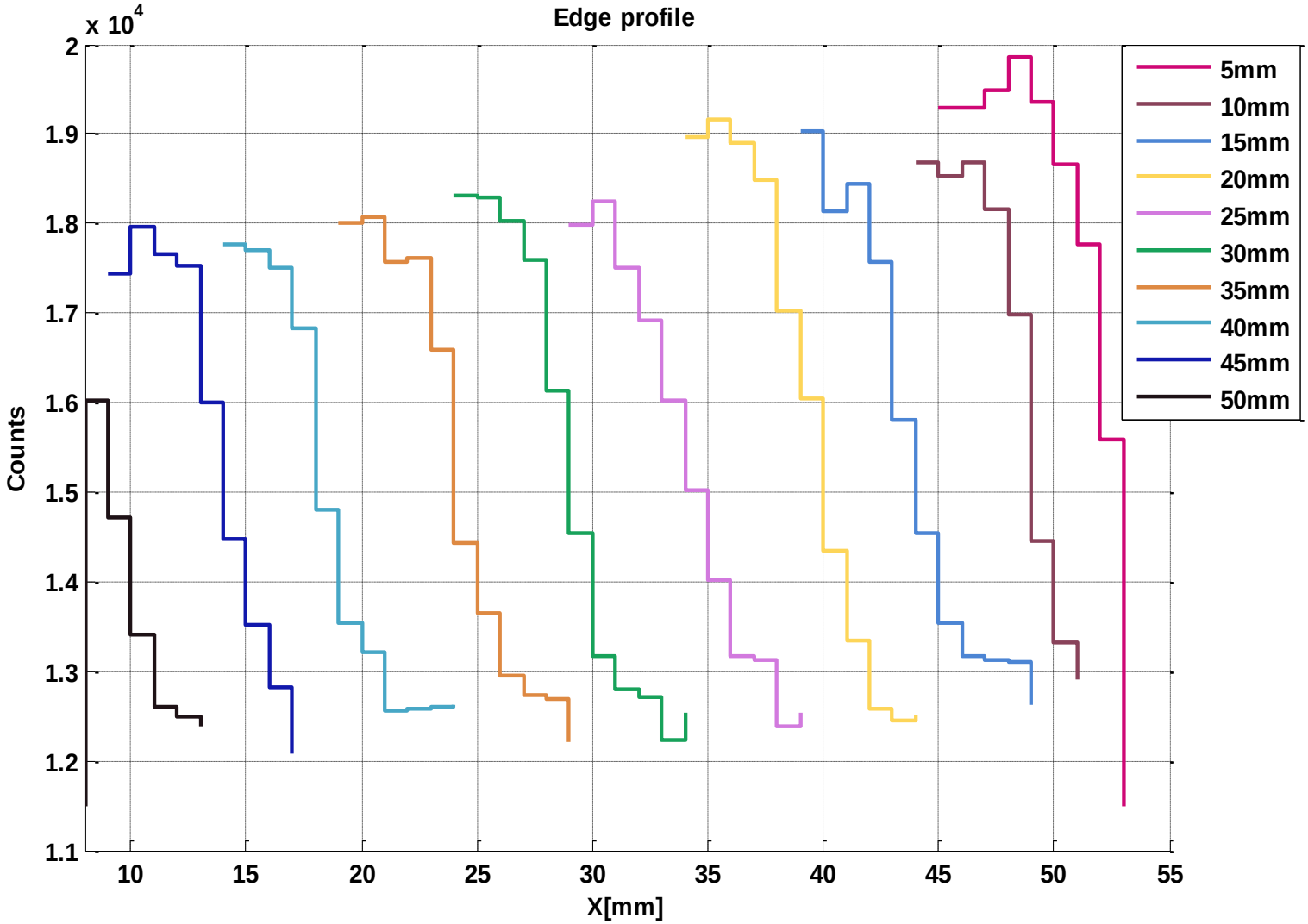


lead block thickness=3cm

1D profile calculation along X: integration on the Y direction (1mm bin)

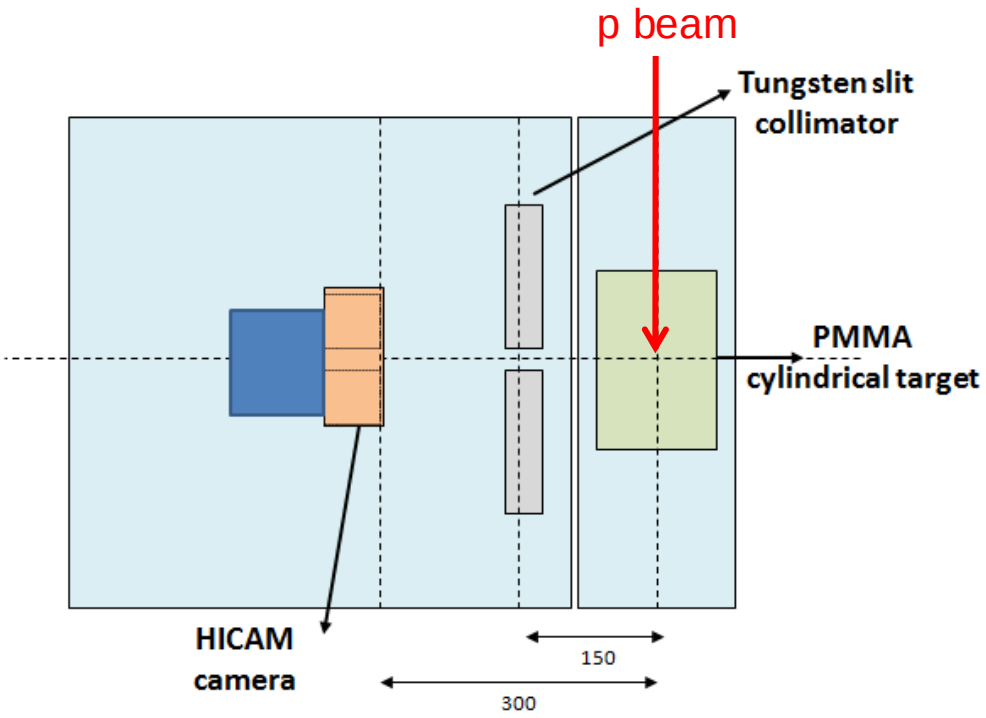


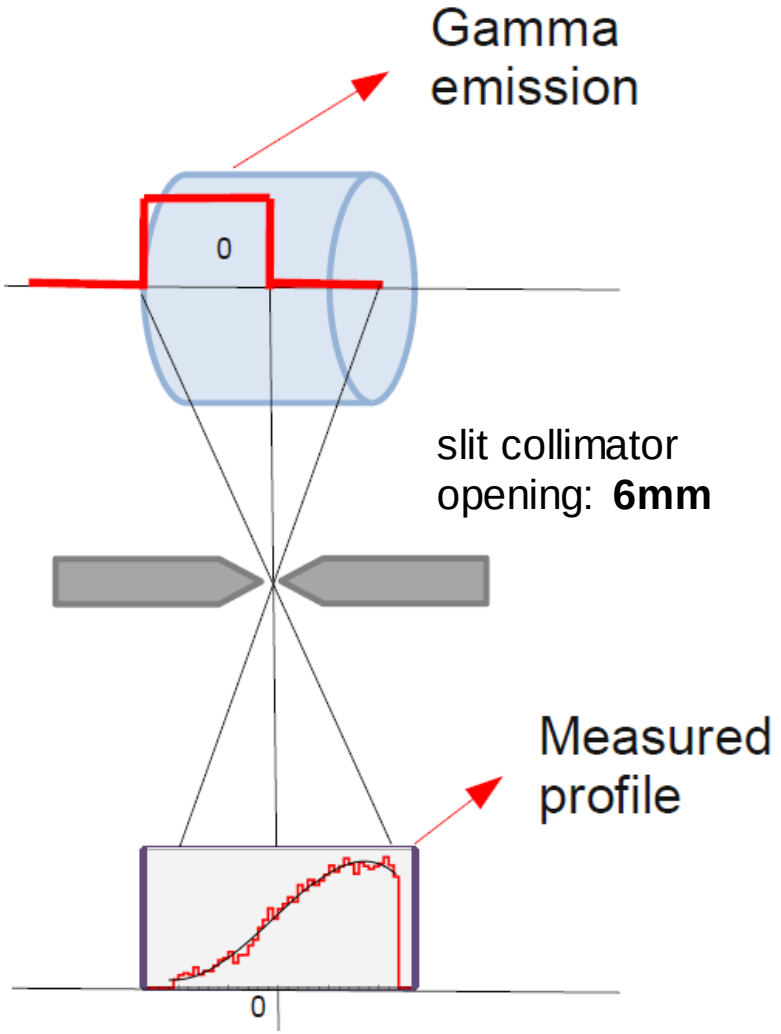
carlo.fiorini@polimi.it
Politecnico di Milano, Italy



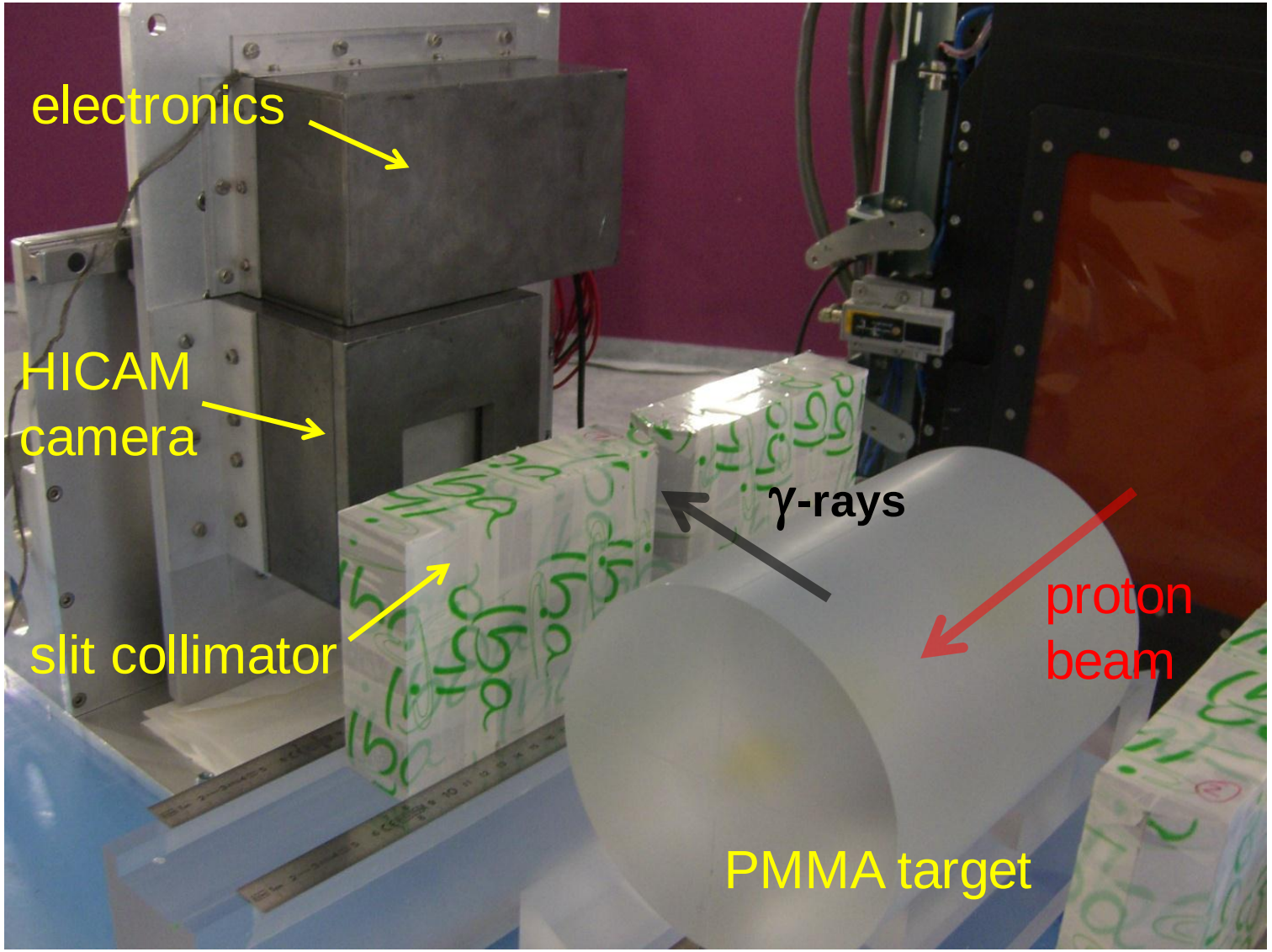
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Proton range measurements: the experimental set-up



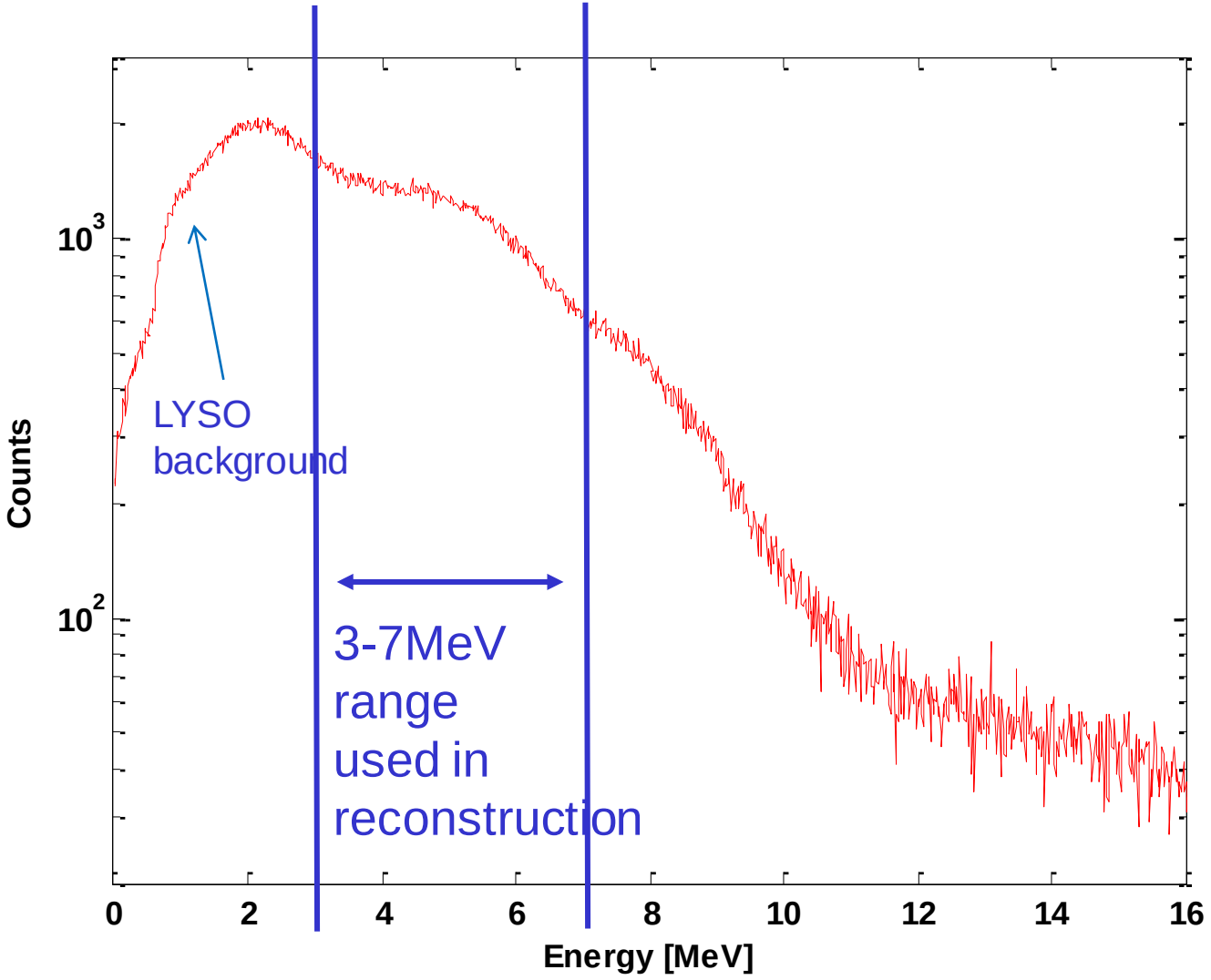


carlo.fiorini@polimi.it
Politecnico di Milano, Italy



carlo.fiorini@polimi.it
Politecnico di Milano, Italy

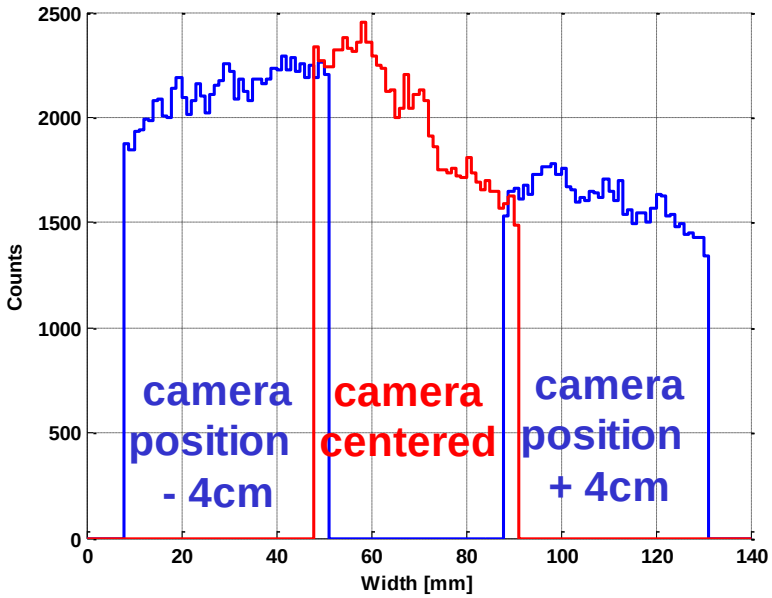
Measured energy spectrum

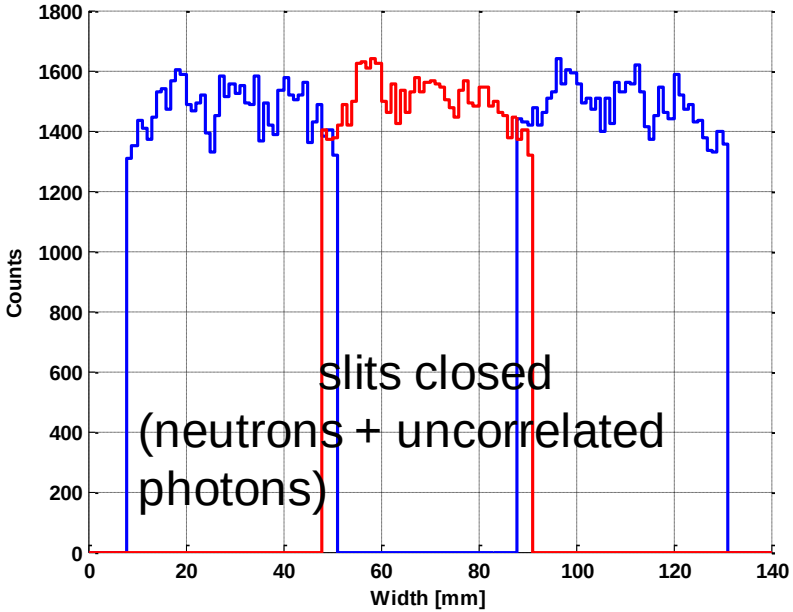


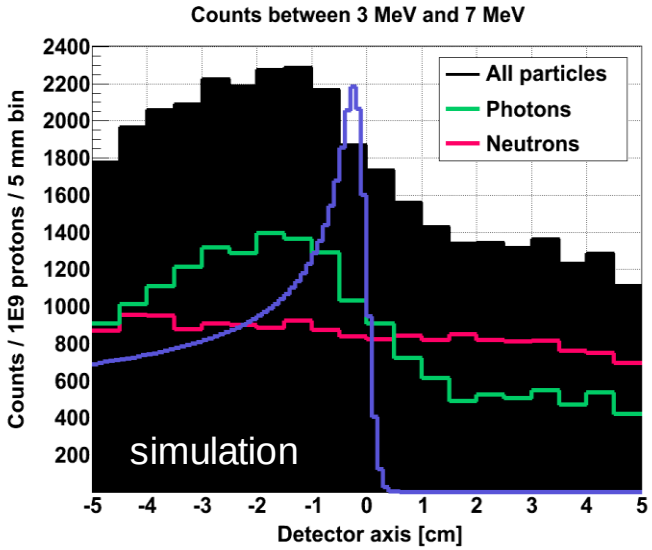
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

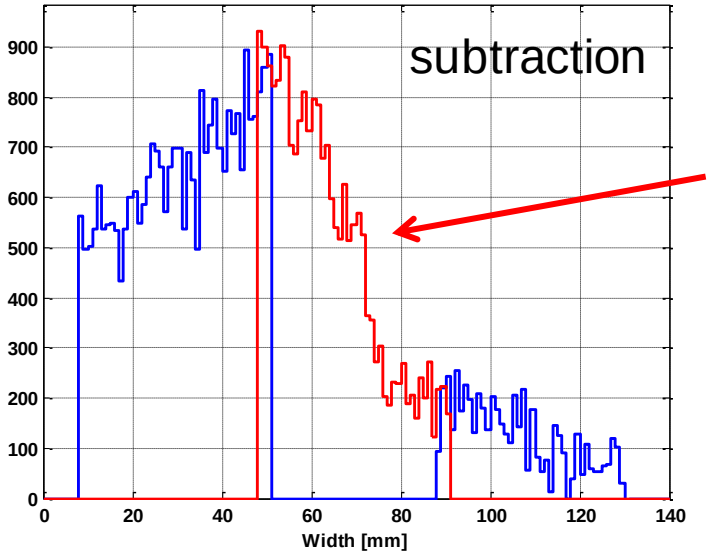
Measured profiles

Beam energy: 160MeV





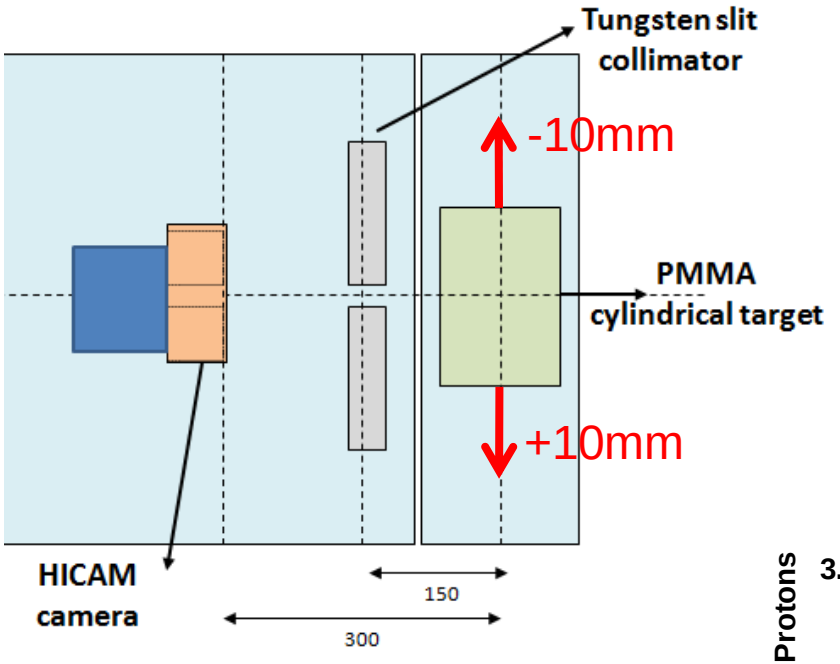


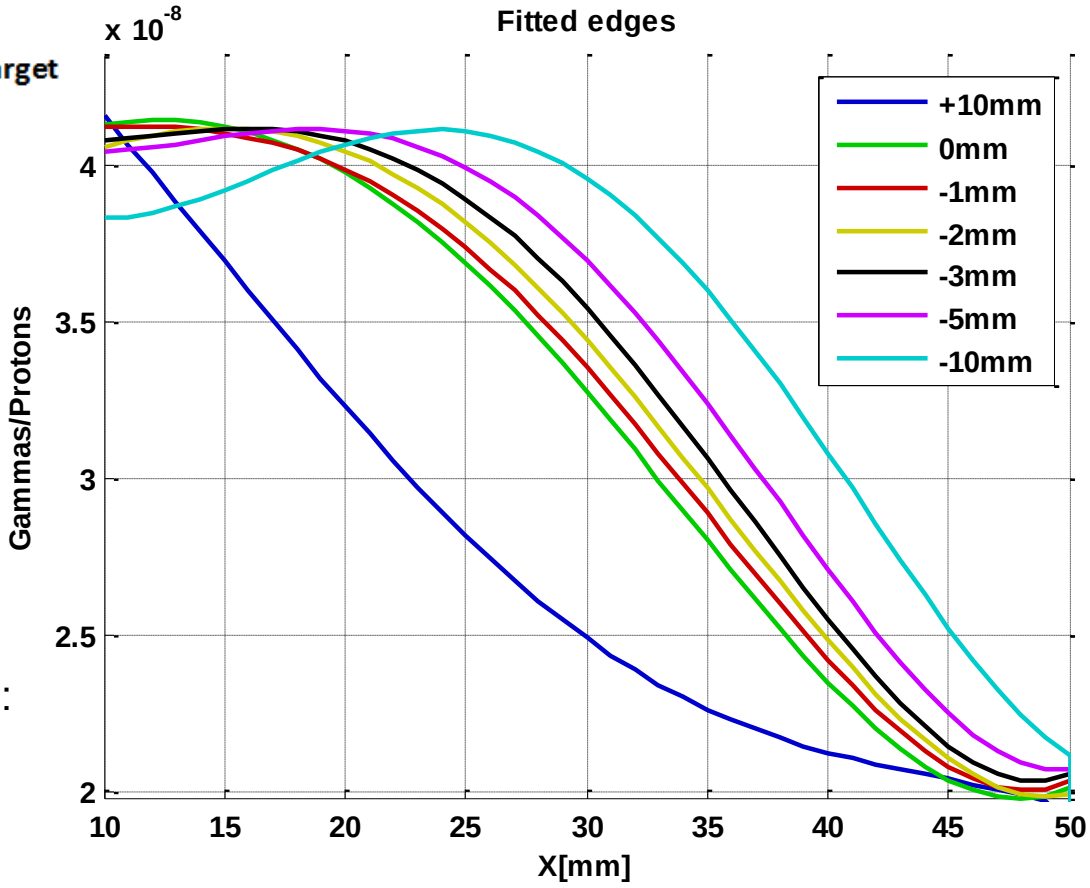


central profile is fitted and monitored while moving the target (and the Bragg-peak)

carlo.fiorini@polimi.it
Politecnico di Milano, Italy

100MeV protons (preliminary analysis)

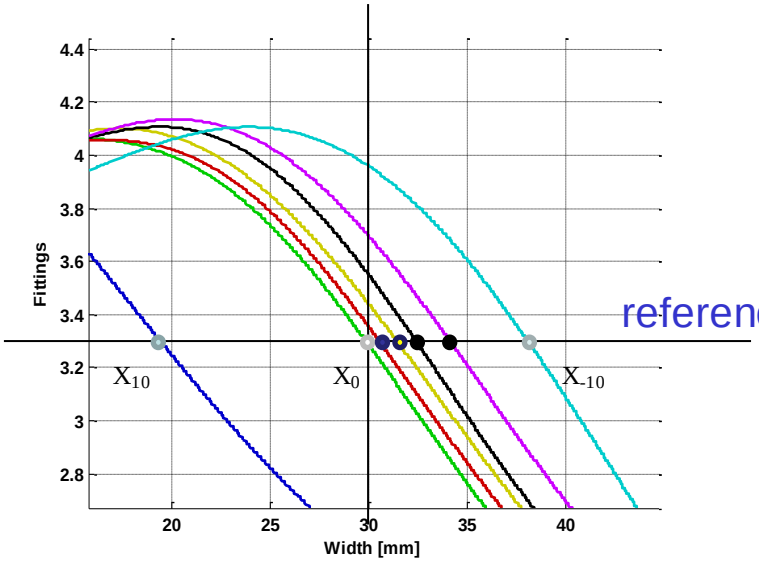




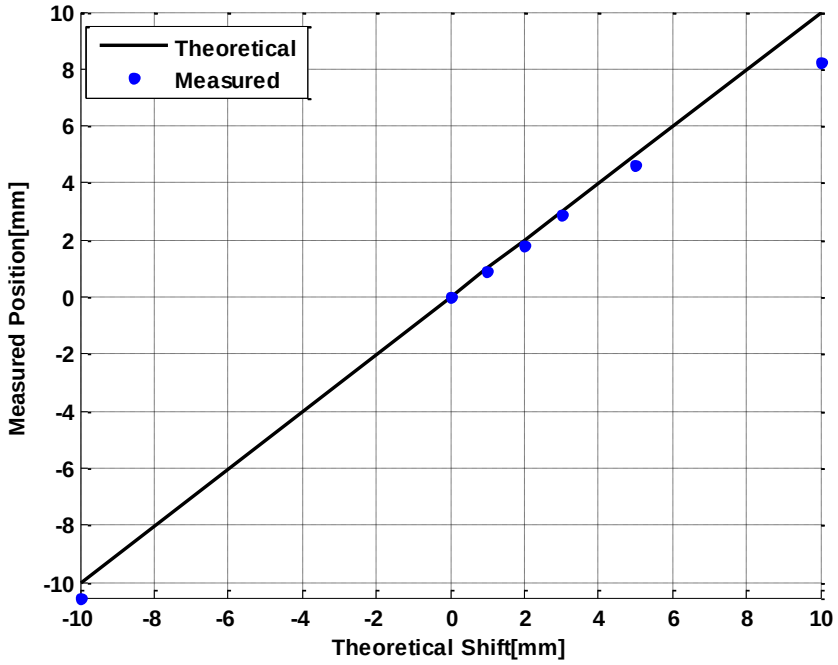
each acquisition:
- 5min.
- $7 \cdot 10^{10}$ protons

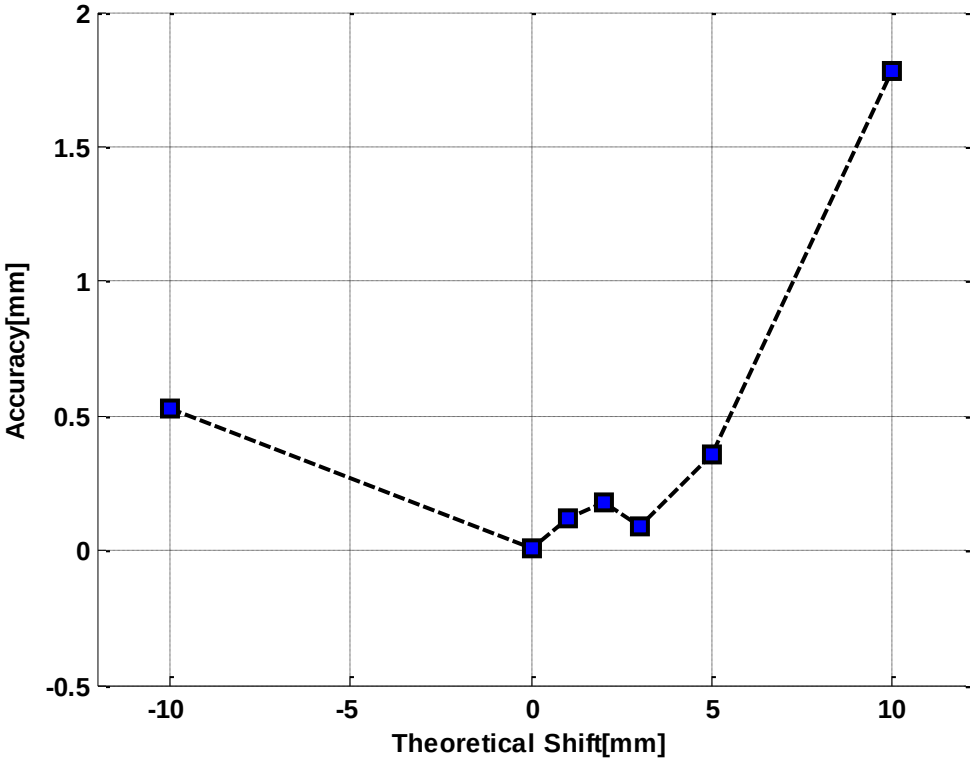
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Shift accuracy



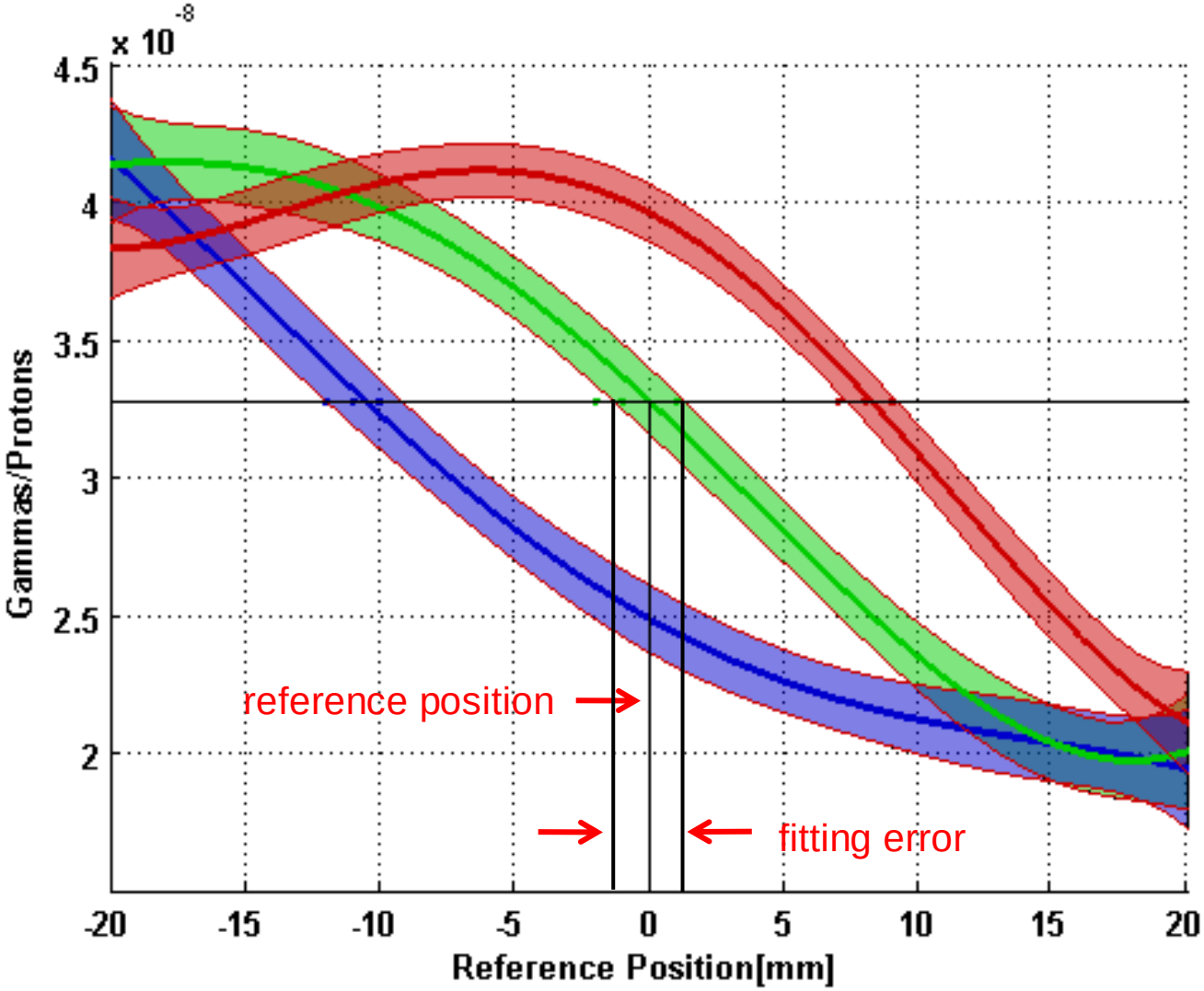
reference value



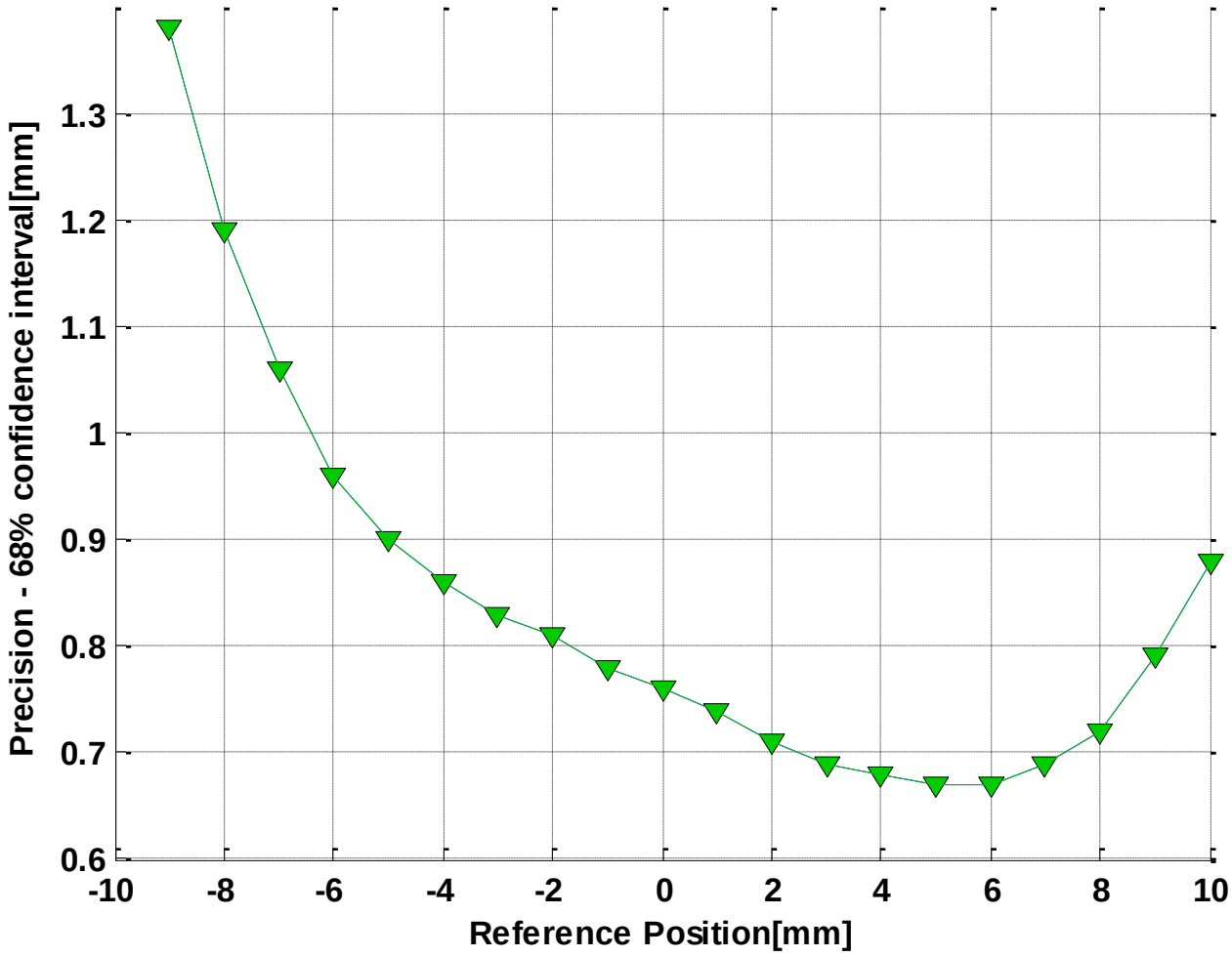


carlo.fiorini@polimi.it
Politecnico di Milano, Italy

Precision

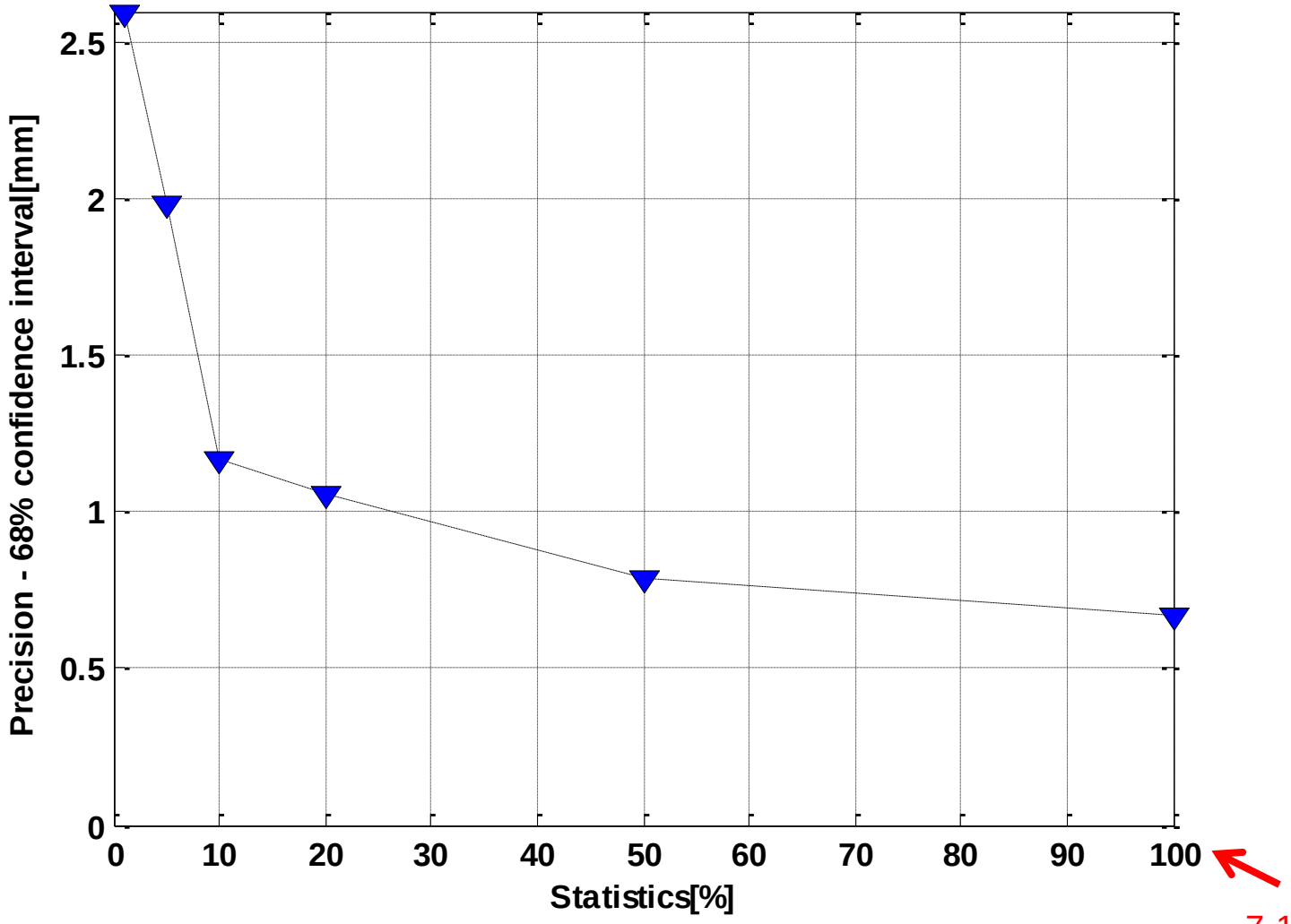


carlo.fiorini@polimi.it
Politecnico di Milano, Italy



carlo.fiorini@polimi.it
Politecnico di Milano, Italy

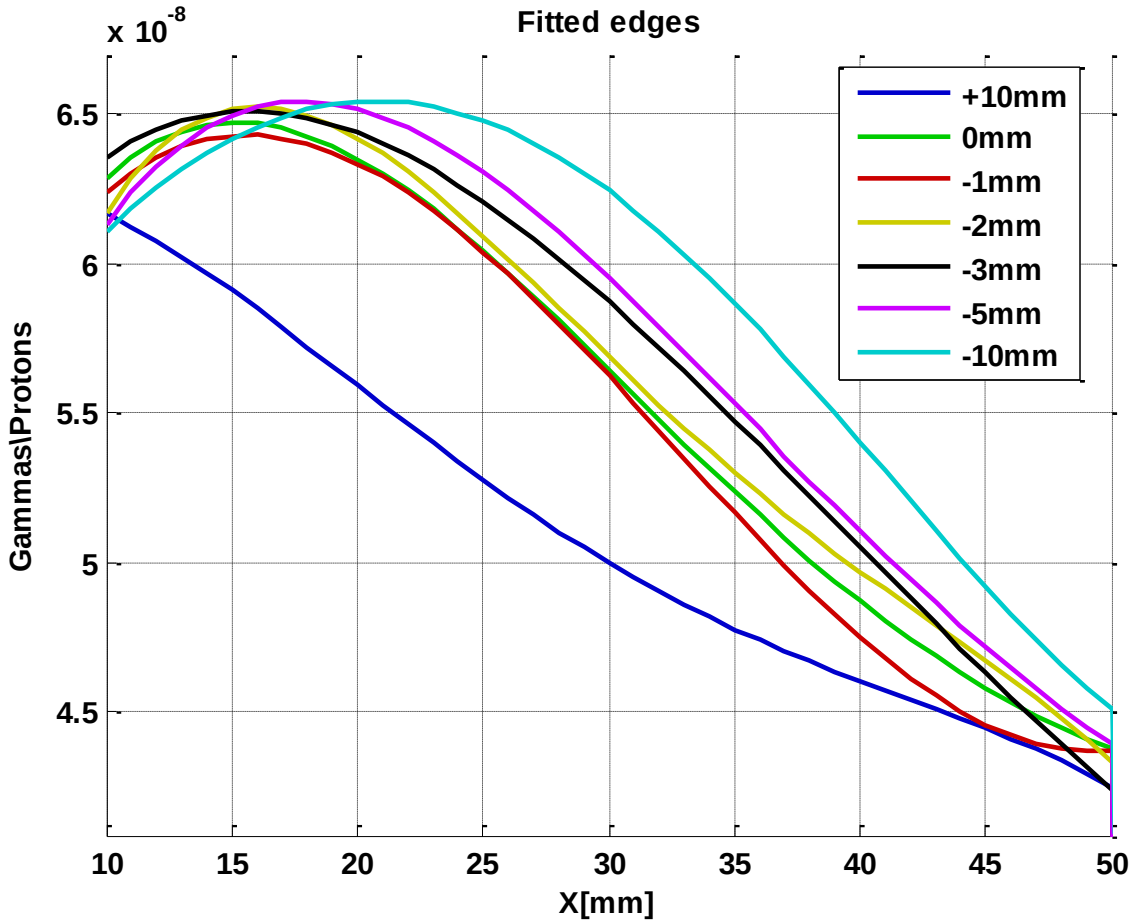
Precision vs. statistics



$7 \cdot 10^{10}$ protons

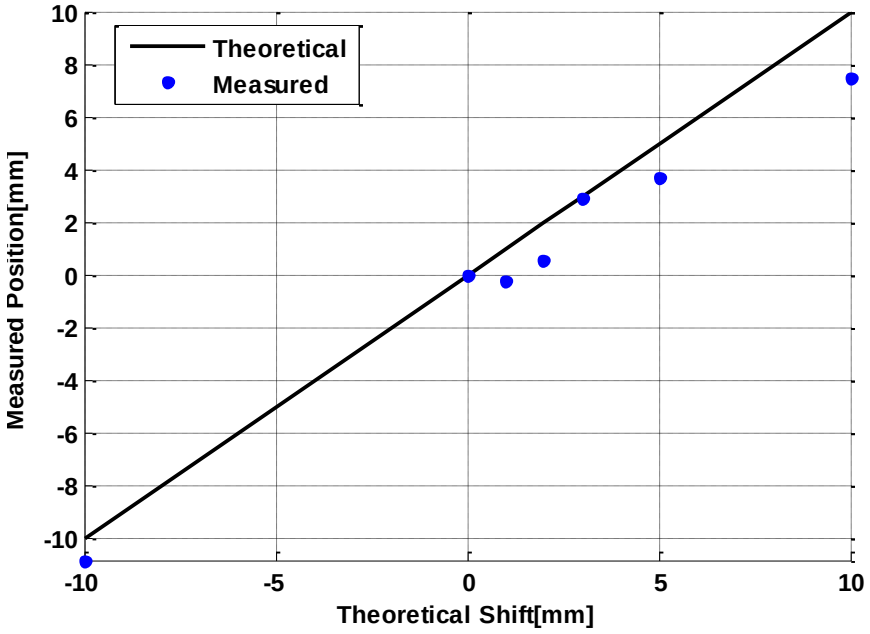
carlo.fiorini@polimi.it
Politecnico di Milano, Italy

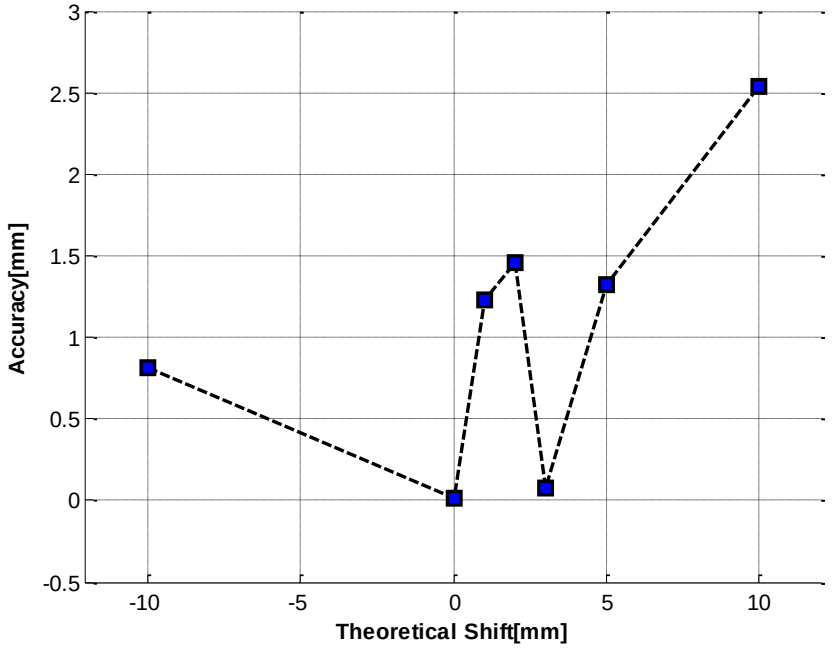
160MeV protons (preliminary analysis)

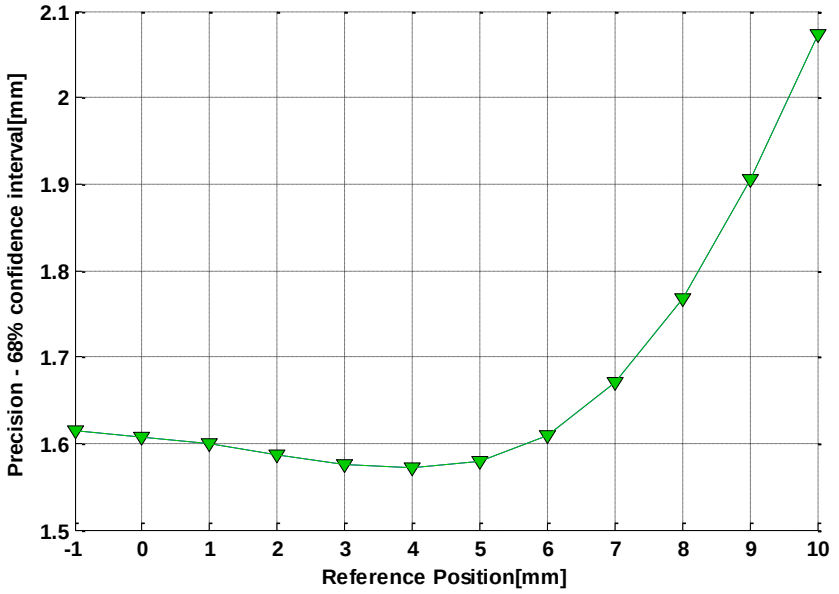


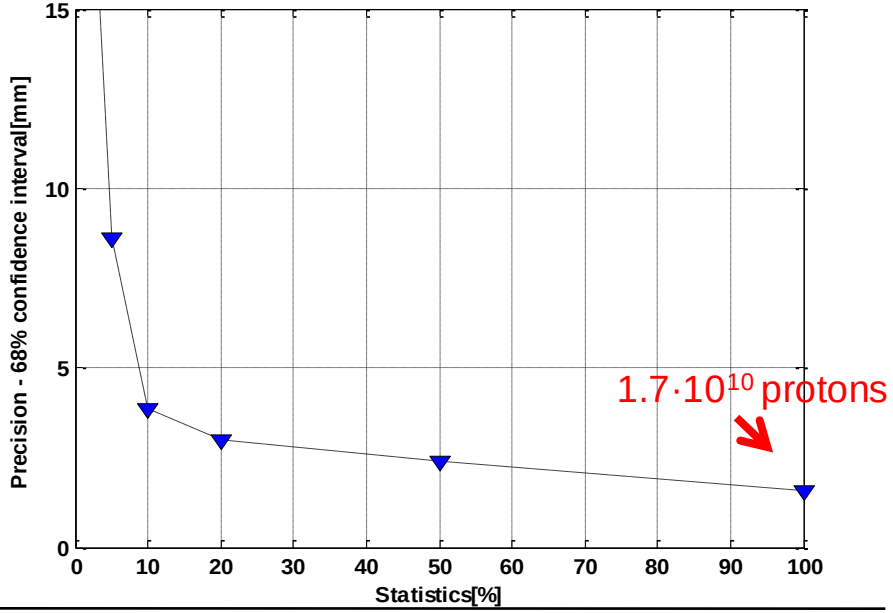
each acquisition:
- 2min.
- $1.7 \cdot 10^{10}$ protons

carlo.fiorini@polimi.it
Politecnico di Milano, Italy









carlo.fiorini@polimi.it
Politecnico di Milano, Italy

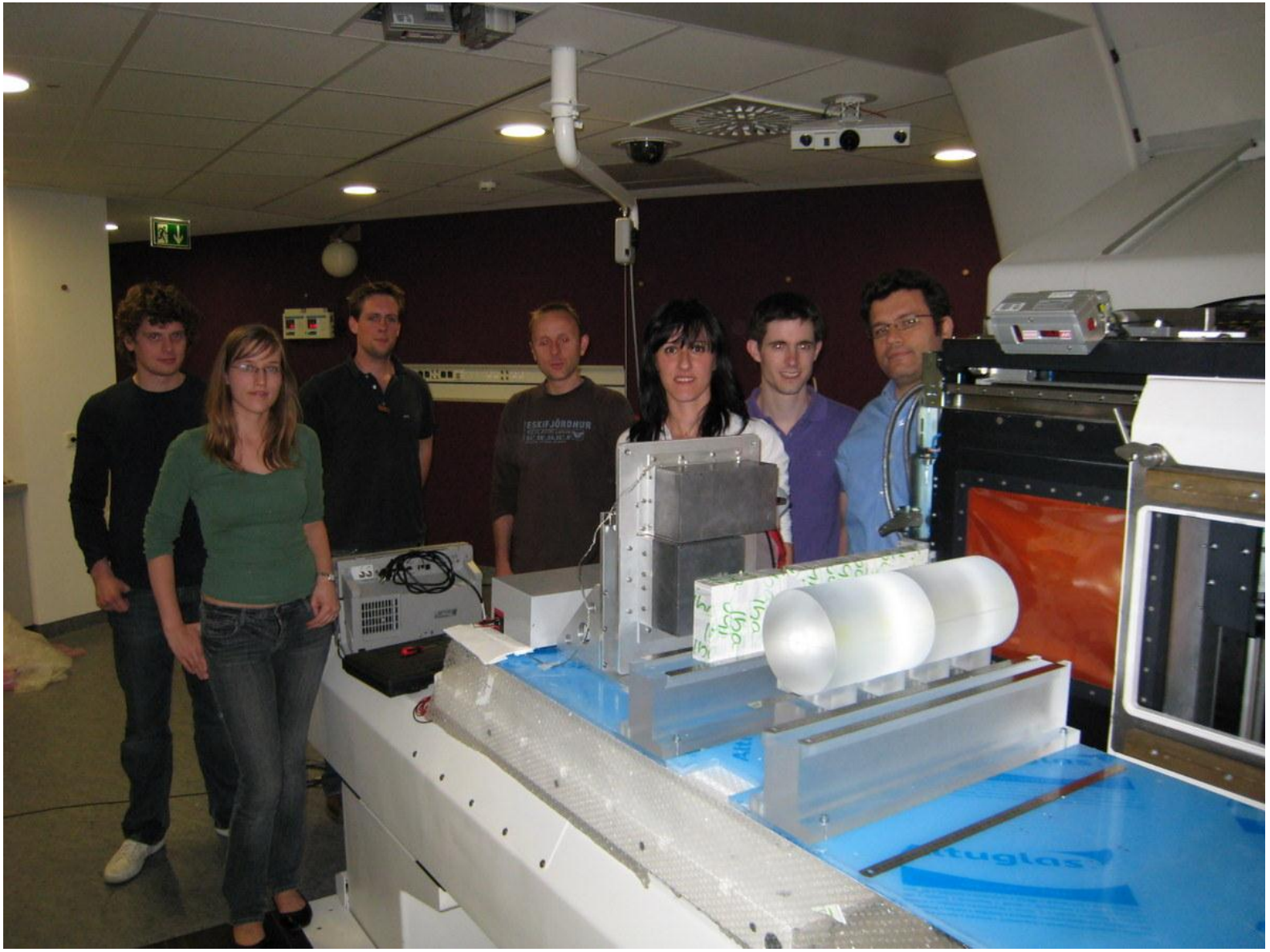
Conclusions

- Measurements of prompt gammas correlated to proton range were successfully made using the HICAM gamma camera
- Although not optimized for 1-10MeV energy range (low efficiency, low scintillator light collection), satisfactory accuracy and precision (in the ‘mm’ range) were first measured

Future work

- Further data analysis also to correlate results to dose expected in patient treatment.
- Measurements to be repeated also with other protons energies (230MeV).
- Gamma camera to be modified/redesigned to improve efficiency and speed

carlo.fiorini@polimi.it
Politecnico di Milano, Italy



carlo.fiorini@polimi.it
Politecnico di Milano, Italy