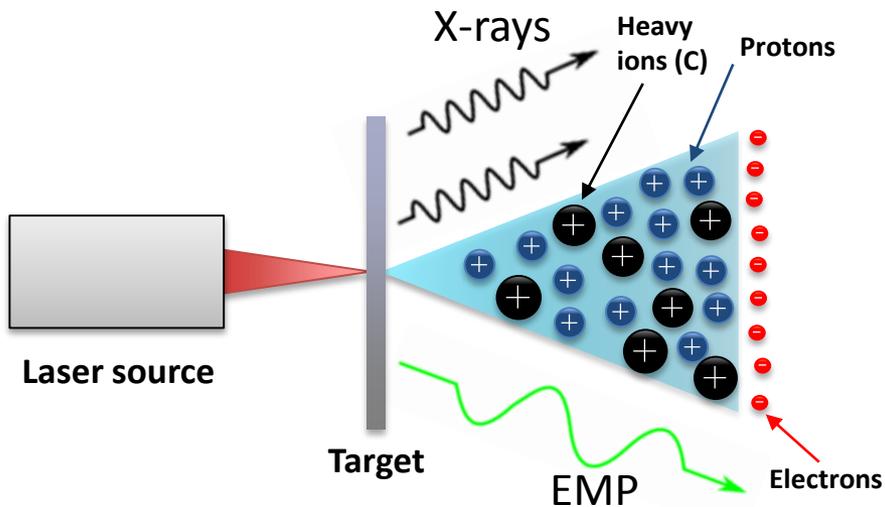# BLIN4

4th Beam Line and INstrumentation Workshop

Laser-driven proton beam diagnostic: feasibility study of a novel technique and possible applications

Davide Vavassori

29/06/2020

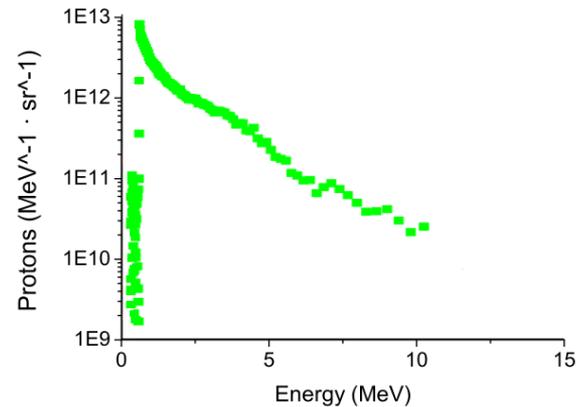# LASER DRIVEN PROTON BEAM DIAGNOSTICS

X-rays
Heavy ions (C)
Protons
Laser source
Target
EMP
Electrons

DIAGNOSTICS

- Real-time energy spectrum measurement
- Discriminate ion species
- Low background sensitivity
- EMP resistant
- No saturation

- Reliable data
- Maximum energy ~ 10 MeV (required for several potential applications)
- High repetition rate

[C. Zulick *et al.*, Appl. Phys. Lett. 102, 2013]

- Discriminates ion species
- Removes electrons
- Provides energy resolved distribution
- Needs position sensitive detector

Protons ——
+
C-ions ——
Pinhole
$\overline{E}$
$\overline{B}$
Magnets
Electric field plates
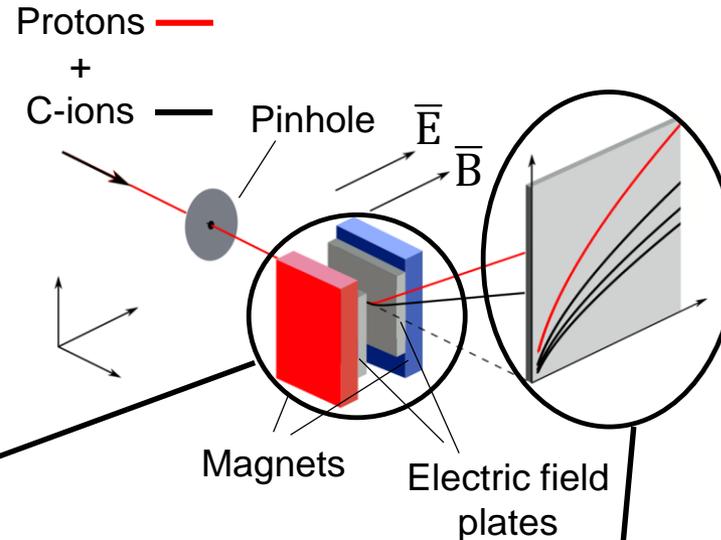
Deviation between nominal and effective fields (fringe fields)
[P. Bolton *et al.,* Phys. Med. 30, 2013]
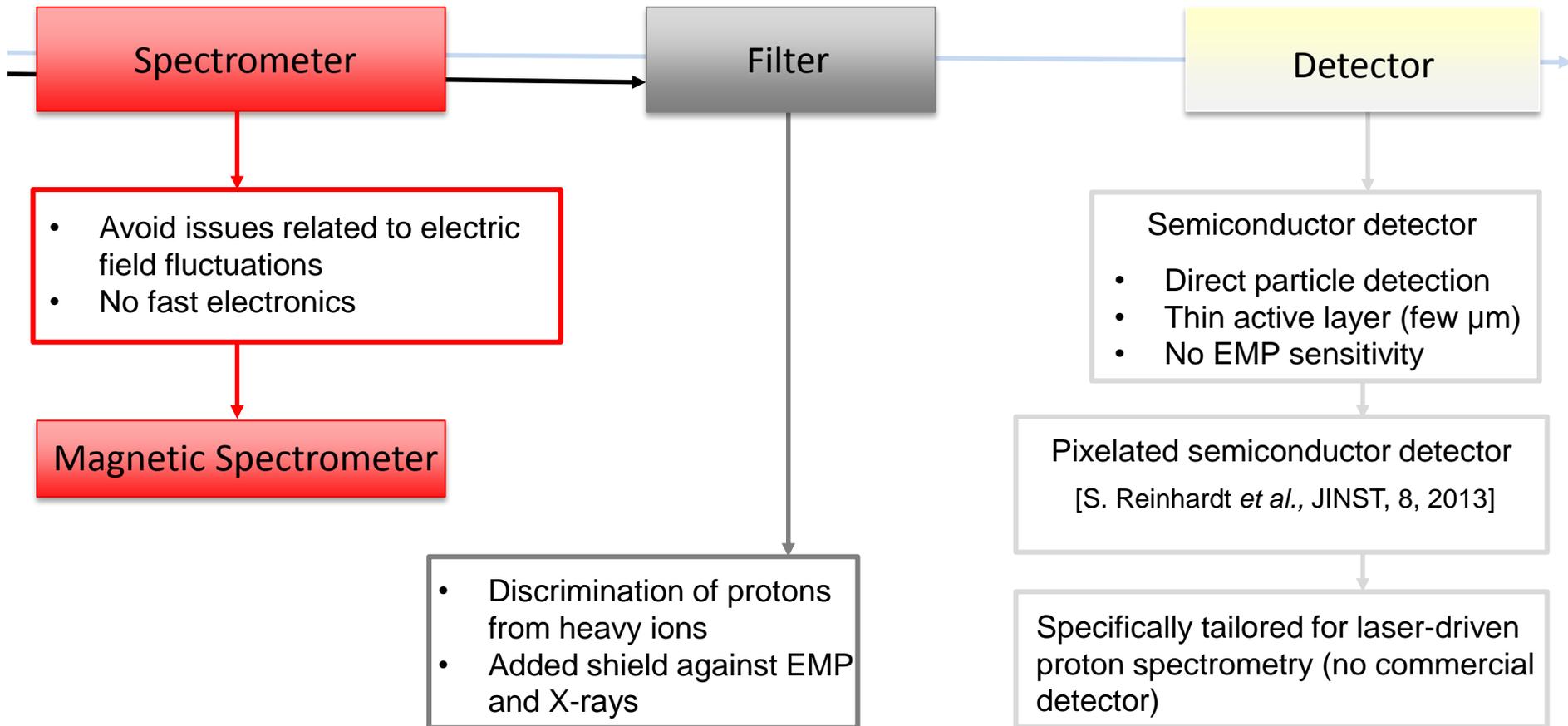[F. Treffert *et al.,* Rev. Sci. Instrum. 89, 2018]

Effective magnetic field constant, while effective electric field fluctuates

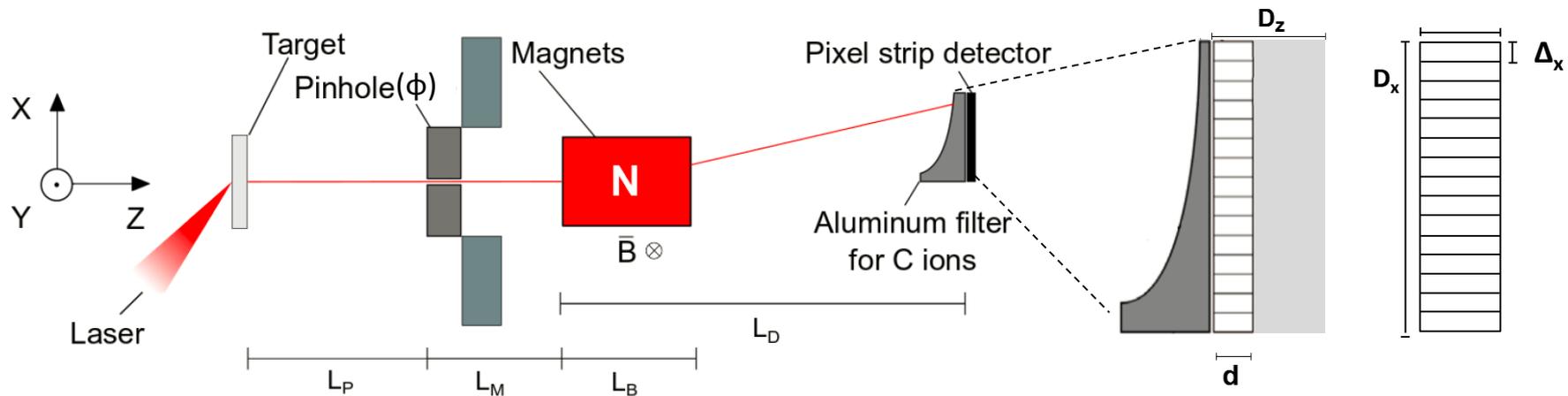Problems related to calibration of the energy-position relationship

Microchannel plate + phosphor screen

- Saturation issues
- Complex and uncertain **absolute calibration**

Spectrometer → **Filter** → **Detector**

Spectrometer:
- Avoid issues related to electric field fluctuations
- No fast electronics

Magnetic Spectrometer

Filter:
- Discrimination of protons from heavy ions
- Added shield against EMP and X-rays

Detector:

Semiconductor detector
- Direct particle detection
- Thin active layer (few µm)
- No EMP sensitivity

Pixelated semiconductor detector

[S. Reinhardt *et al.,* JINST, 8, 2013]

Specifically tailored for laser-driven proton spectrometry (no commercial detector)

PROPOSED DETECTION SYSTEM

THEORETICAL STUDY →
- Develop a solid theoretical basis
- Study the feasibility of the reconstruction technique
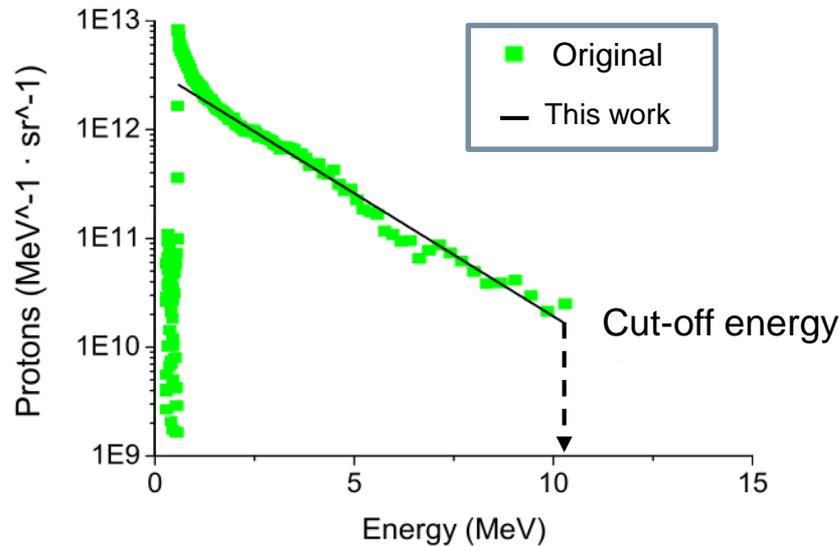
Analytical model of the detection system

- Transport inside the MS
- Detection stage ⟷ **Monte Carlo simulations (FLUKA)**
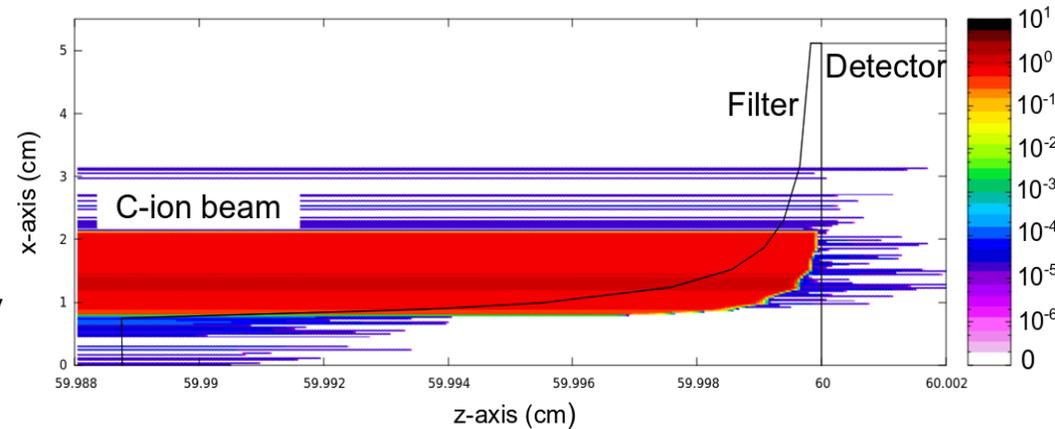
DETECTION SYSTEM SIMULATIONS

MODELING OF THE PROTON SPECTRUM

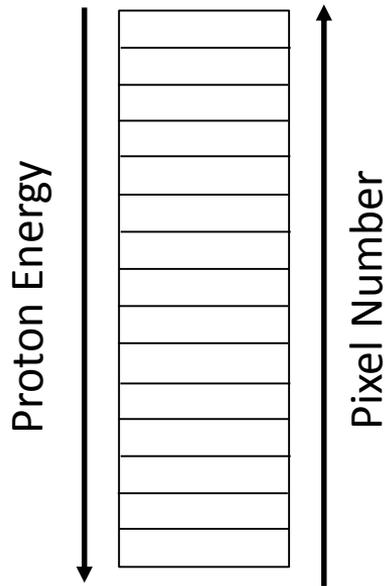- Quasi-exponential trend
- Maximum energy ~ 10 MeV

  Implemented as the source spectrum in FLUKA

MODELING OF THE FILTER

- Filter thickness profile derived analytically (1.7-115 μm)
- Implemented complex filter profile in FLUKA
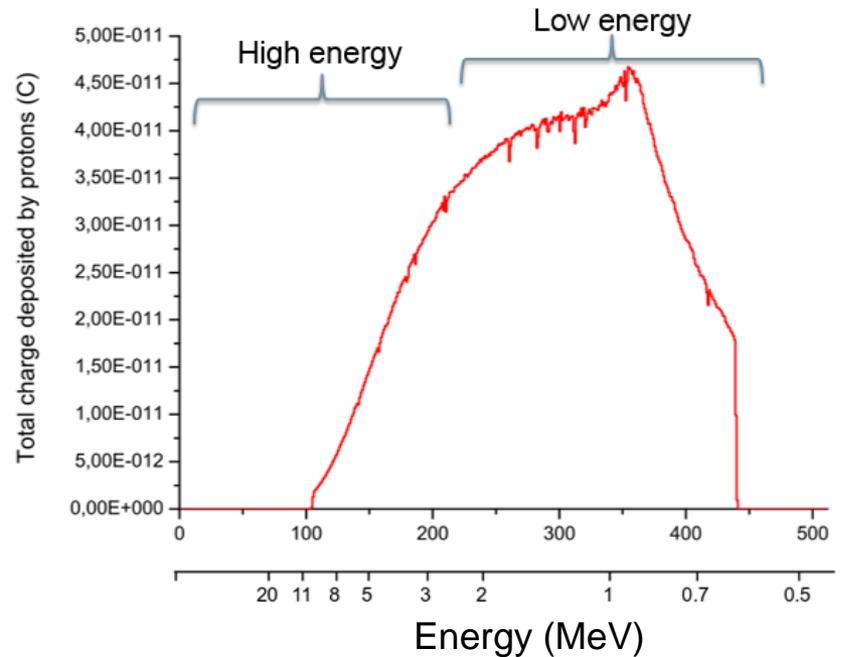- Tested with non monochromatic C-ion beam

Determination of **proton energy**

Derived analytically

- Energy bin is assigned to each pixel
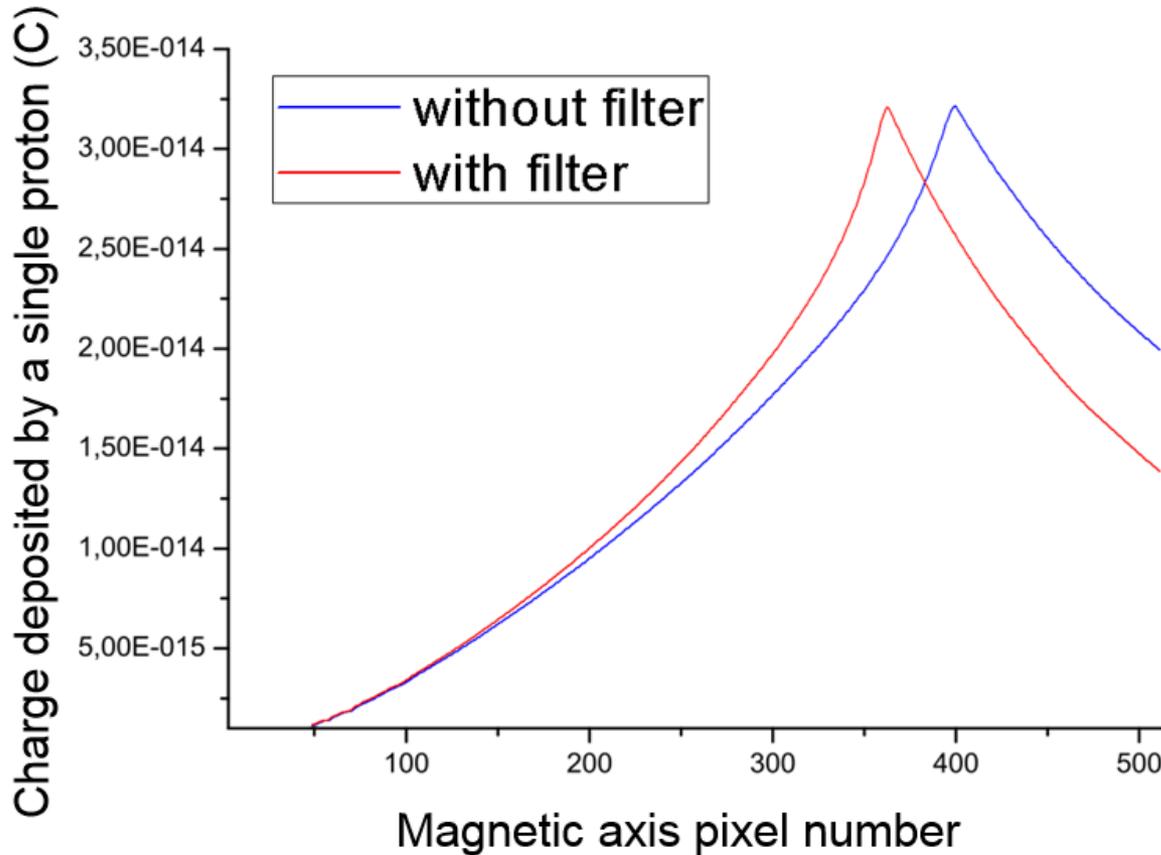- Each pixel integrates total deposited charge

Derived numerically

- It is the quantity that would be measured in an experiment
- Gradient in deposited charge over the whole spectrum

Solution: Front-end electronics modulated along the magnetic axis

Determination of the **total charge**

Analytical part

- SRIM software was employed

Numerical part

- Simulations performed on single pixels

- Introduces particle straggling

Dividing the total charge by the single proton charge ⟶ **Number of protons**
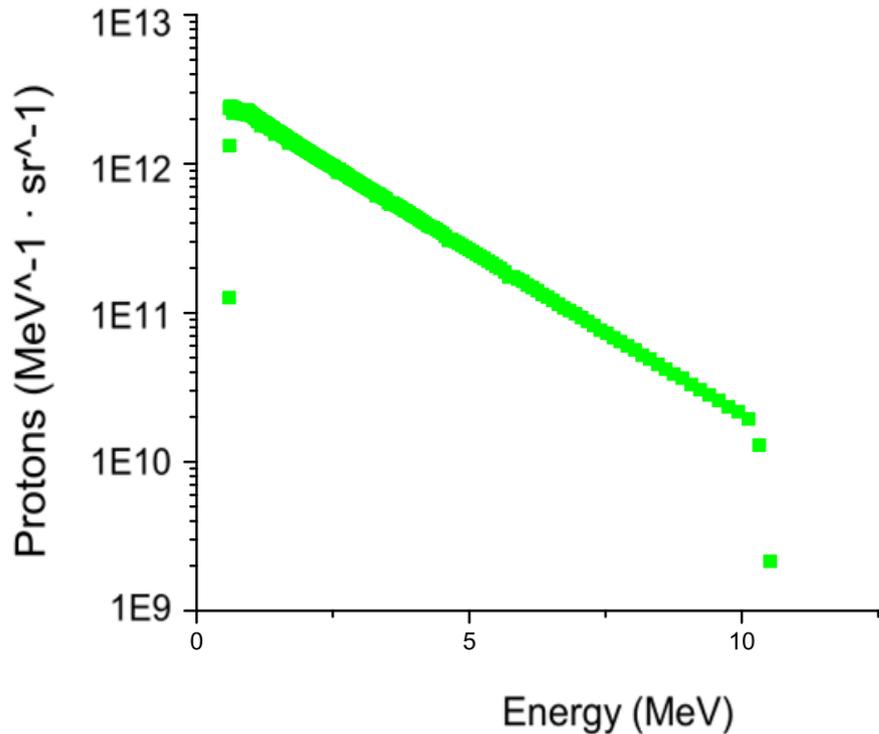
Combining the information obtained in the different previous steps, the proton spectrum can be reconstructed

$\longrightarrow$

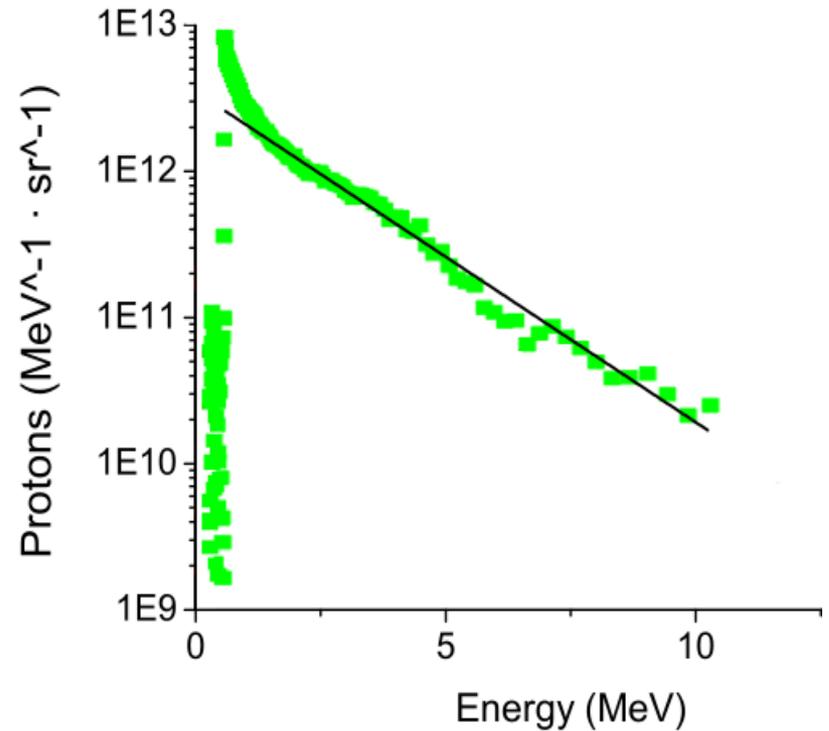✓ Shows **theoretical feasibility**
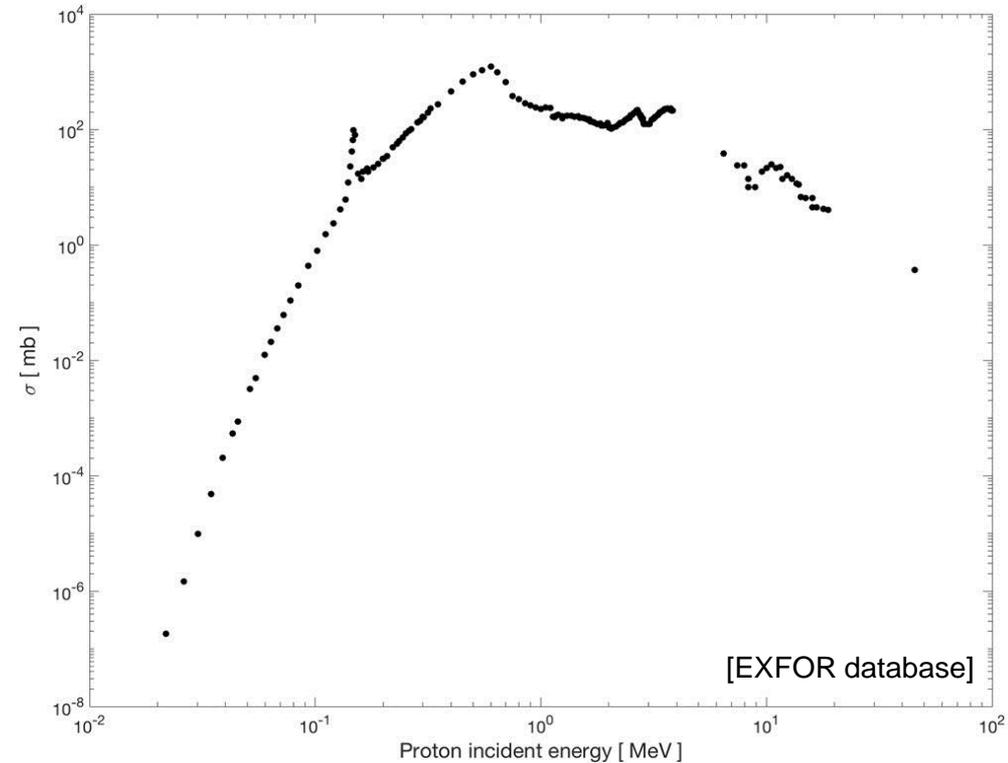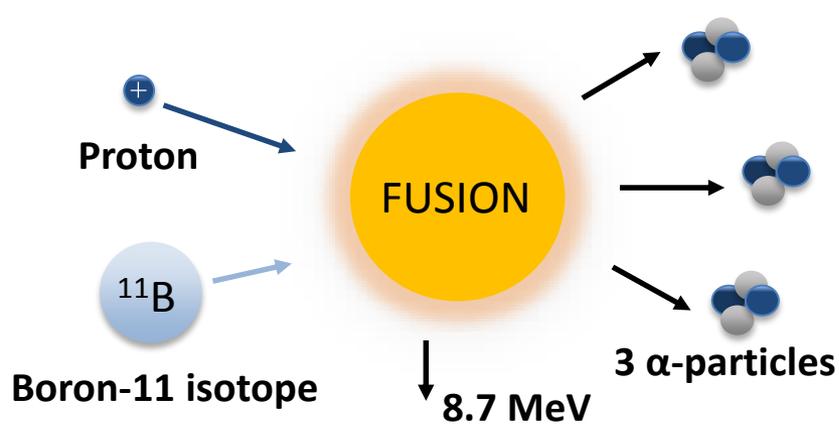
[G. Milluzzo *et al.,* Rev. Sci. Instrum., 90, 2019]

Reconstructed

Original

Proton

^{11}B

Boron-11 isotope

FUSION

8.7 MeV

3 α-particles

[EXFOR database]

- Energy applications
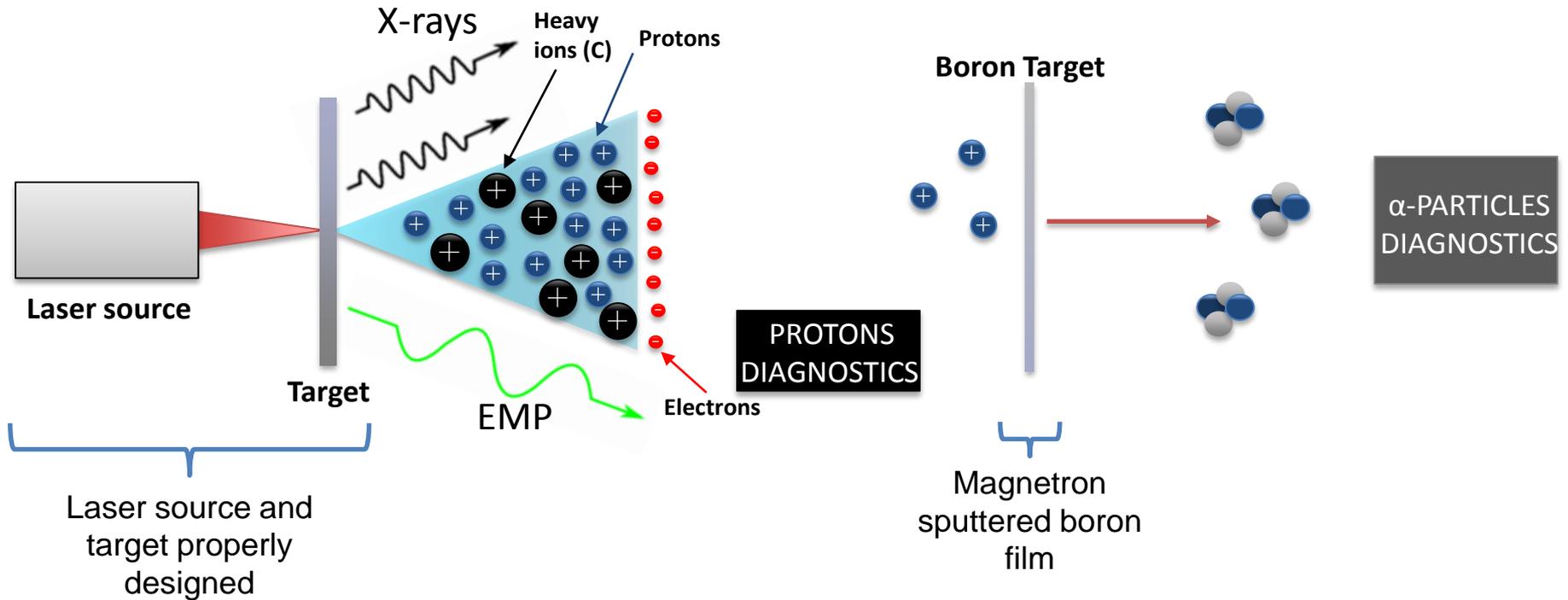[H. Hora *et al.*, Laser Part. Beams 33, 2015]
- Medical applications
[G. A. P. Cirrone *et al.*, Sci. Rep. 8, 2018]
[NEPTUNE project (INFN)]

Main resonance peak occurring approximately at 670 keV proton energy (σ≈1.2barn)

Further studies on the reaction cross section are needed

Laser source and target properly designed

Exponential trend of laser-driven proton energy could be beneficial to study the reaction

- Proton energy is well characterized
- Proton number is well characterized

More in-depth study of the reaction

CONCLUSION AND FUTURE PERSPECTIVES

CONCLUSIONS

- An alternative laser-driven proton beam diagnostic has been proposed and it has been studied combining an analytical model and numerical simulations.

- The detection system has a properly designed filter (selection stage).

- Presence of a modular front-end electronics, but no fast electronics.

- The theoretical feasibility of the reconstruction technique was demonstrated.

PERSPECTIVES

- Analytical model can be used to analyze future experimental data and to design a real spectrometer.

- Experiments involving irradiation of a prototype system, based on a detector with a small number of pixels in a well-defined geometry, are needed.

- Realization of the proposed laser-driven proton beam diagnostic.

- Application in experiments requiring precise beam characterization.

Team@POLIMI

Matteo Passoni	Davide Bortot	David Dellasega
Andrea Pola	Davide Mazzucconi	Francesco Casamichiela

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NanoLab

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Thank you for your kind attention!