# RIPTIDE: a novel recoil-proton track imaging detector for fast neutrons

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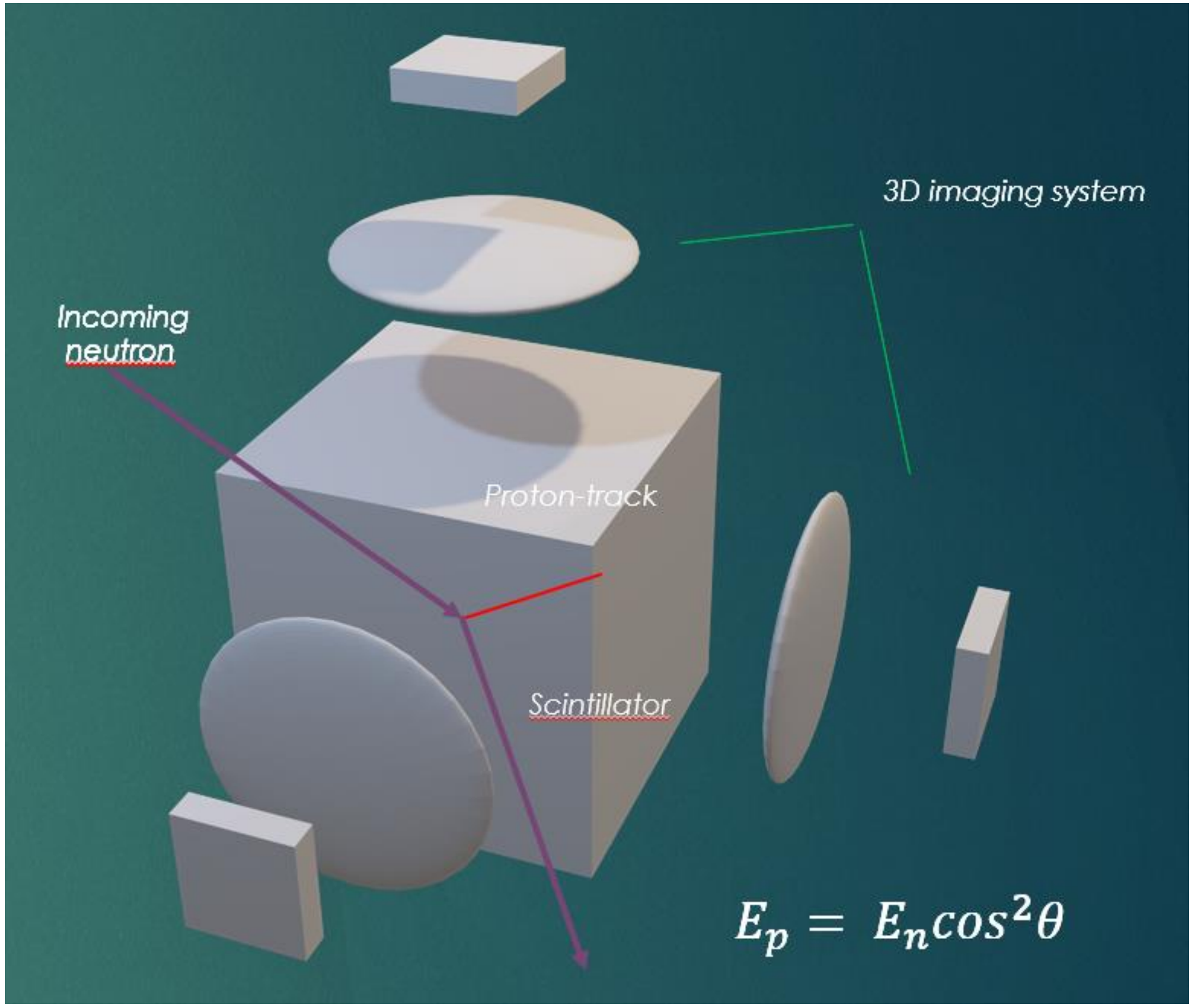
Project started on 2020 within the ***n_TOF* collaboration**

«*neutron scattering length measurement*»

***A. Musumarra & C. Massimi***

CERN-INTC-2020-051 ; INTC-I-220

It has been approved by CSN V INFN on september 2023



# «RIPTIDE» in progress

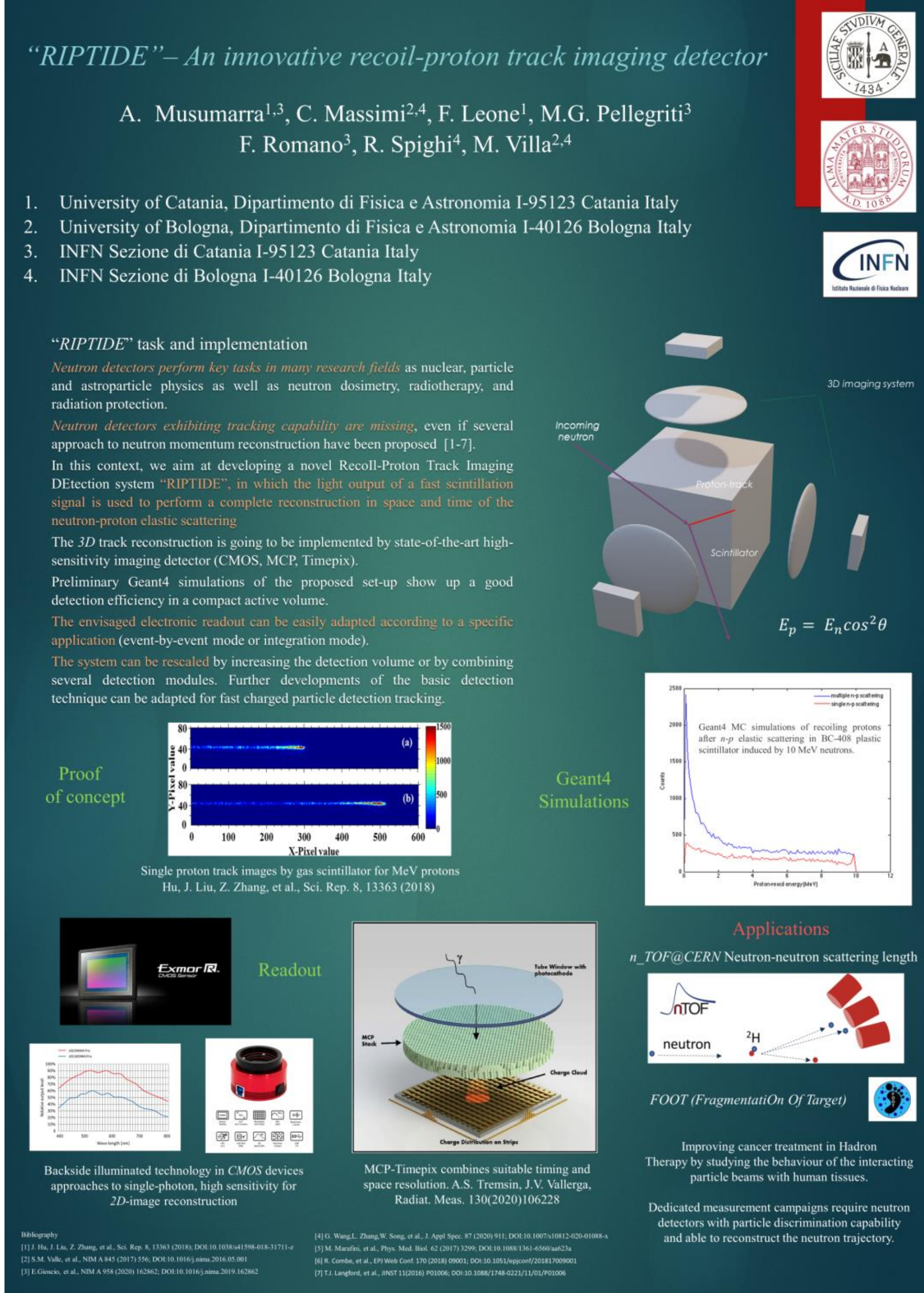
***INFN-CT & INFN-BO***

***Following the progress report by JINST:***

Musumarra, A., Leone, F., Massimi, C., Pellegriti, M., Romano, F., Spighi, R., & Villa, M. (**2021**). RIPTIDE: a novel recoil-proton track imaging detector for fast neutrons. *Journal of Instrumentation, 16(12), C12013.*

Massimi, C., Musumarra, A., Leone, F., Pellegriti, M., Romano, F., Spighi, R., & Villa, M. (**2022**). “RIPTIDE”—an innovative recoil-proton track imaging detector. *Journal of Instrumentation, 17(09), C09026.*

Console Camprini, P., Leone, F., Massimi, C., Musumarra, A., Pellegriti, M., Pisanti, C., Romano, F., Spighi, R., Terranova, N., & Villa, M. (**2023**). A proton-recoil track imaging system for fast neutrons: the RIPTIDE detector. *Journal of Instrumentation, 18(1), C01054.*



## *“RIPTIDE”– An innovative recoil-proton track imaging detector*

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### “*RIPTIDE*” task and implementation

*Neutron detectors perform key tasks in many research fields* as nuclear, particle and astroparticle physics as well as neutron dosimetry, radiotherapy, and radiation protection.

*Neutron detectors exhibiting tracking capability are missing*, even if several approach to neutron momentum reconstruction have been proposed [1-7].

In this context, we aim at developing a novel RecoIl-Proton Track Imaging DEtection system “RIPTIDE”, in which the light output of a fast scintillation signal is used to perform a complete reconstruction in space and time of the neutron-proton elastic scattering

The *3D* track reconstruction is going to be implemented by state-of-the-art high-sensitivity imaging detector (CMOS, MCP, Timepix).

Preliminary Geant4 simulations of the proposed set-up show up a good detection efficiency in a compact active volume.

The envisaged electronic readout can be easily adapted according to a specific application (event-by-event mode or integration mode).

The system can be rescaled by increasing the detection volume or by combining several detection modules. Further developments of the basic detection technique can be adapted for fast charged particle detection tracking.

$$E_p = E_n cos^2\theta$$

Proof of concept

Single proton track images by gas scintillator for MeV protons
Hu, J. Liu, Z. Zhang, et al., Sci. Rep. 8, 13363 (2018)

Geant4 Simulations

Geant4 MC simulations of recoiling protons after *n-p* elastic scattering in BC-408 plastic scintillator induced by 10 MeV neutrons.

Readout

Backside illuminated technology in *CMOS* devices approaches to single-photon, high sensitivity for *2D*-image reconstruction

MCP-Timepix combines suitable timing and space resolution. A.S. Tremsin, J.V. Vallerga, Radiat. Meas. 130(2020)106228

### Applications

*n_TOF@CERN* Neutron-neutron scattering length

*FOOT (FragmentatiOn Of Target)*

Improving cancer treatment in Hadron Therapy by studying the behaviour of the interacting particle beams with human tissues.

Dedicated measurement campaigns require neutron detectors with particle discrimination capability and able to reconstruct the neutron trajectory.

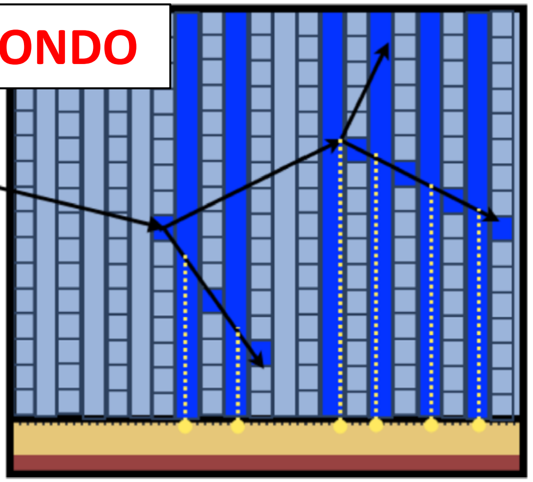
Bibliography
[1] J. Hu, J. Liu, Z. Zhang, et al., Sci. Rep. 8, 13363 (2018); DOI:10.1038/s41598-018-31711-z
[2] S.M. Valle, et al., NIM A 845 (2017) 556; DOI:10.1016/j.nima.2016.05.001
[3] E.Gioscio, et al., NIM A 958 (2020) 162862; DOI:10.1016/j.nima.2019.162862
[4] G. Wang,L. Zhang,W. Song, et al., J. Appl Spec. 87 (2020) 911; DOI:10.1007/s10812-020-01088-x
[5] M. Marafini, et al., Phys. Med. Biol. 62 (2017) 3299; DOI:10.1088/1361-6560/aa623a
[6] R. Combe, et al., EPJ Web Conf. 170 (2018) 09001; DOI:10.1051/epjconf/201817009001
[7] T.J. Langford, et al., JINST 11(2016) P01006; DOI:10.1088/1748-0221/11/01/P01006

# *State of the art*

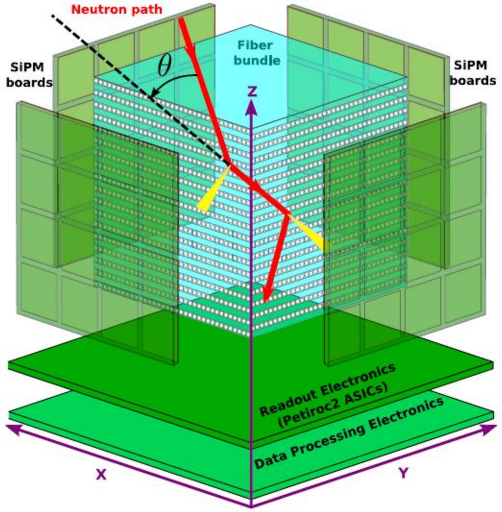
*Lower efficiency large n-energy threshold*

## Neutron track Imaging with Single and Double scattering

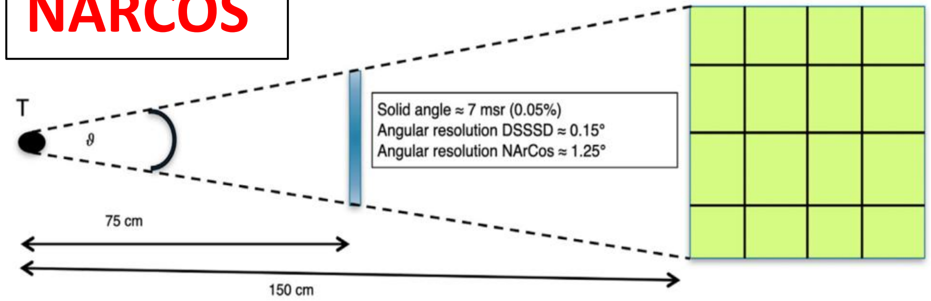
**MONDO**



**SONTRAC**

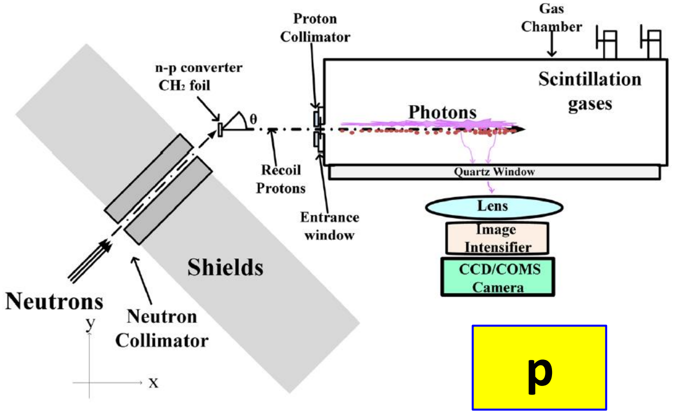


**NARCOS**



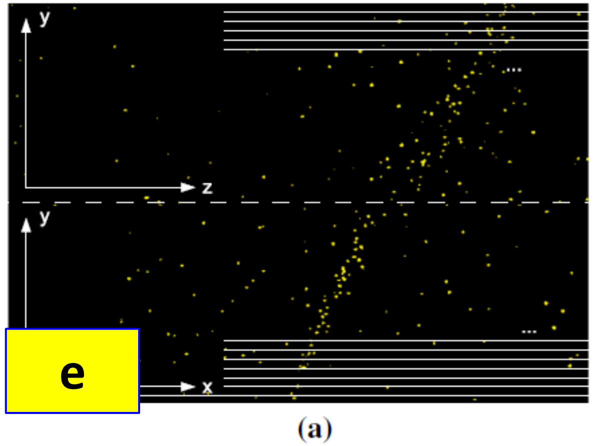
M. Marafini, *et al.*, Phys. Med. Biol. **62** (2017) 3299
G.A. de Nolfo, et al. NIMA 1054 (2023) 168352
E.V. Pagano, et al. Frontiers of physics, DOI 10.3389/fphy.2022.1051058

## Optical system to track particles (*p, e, μ*)



**p**

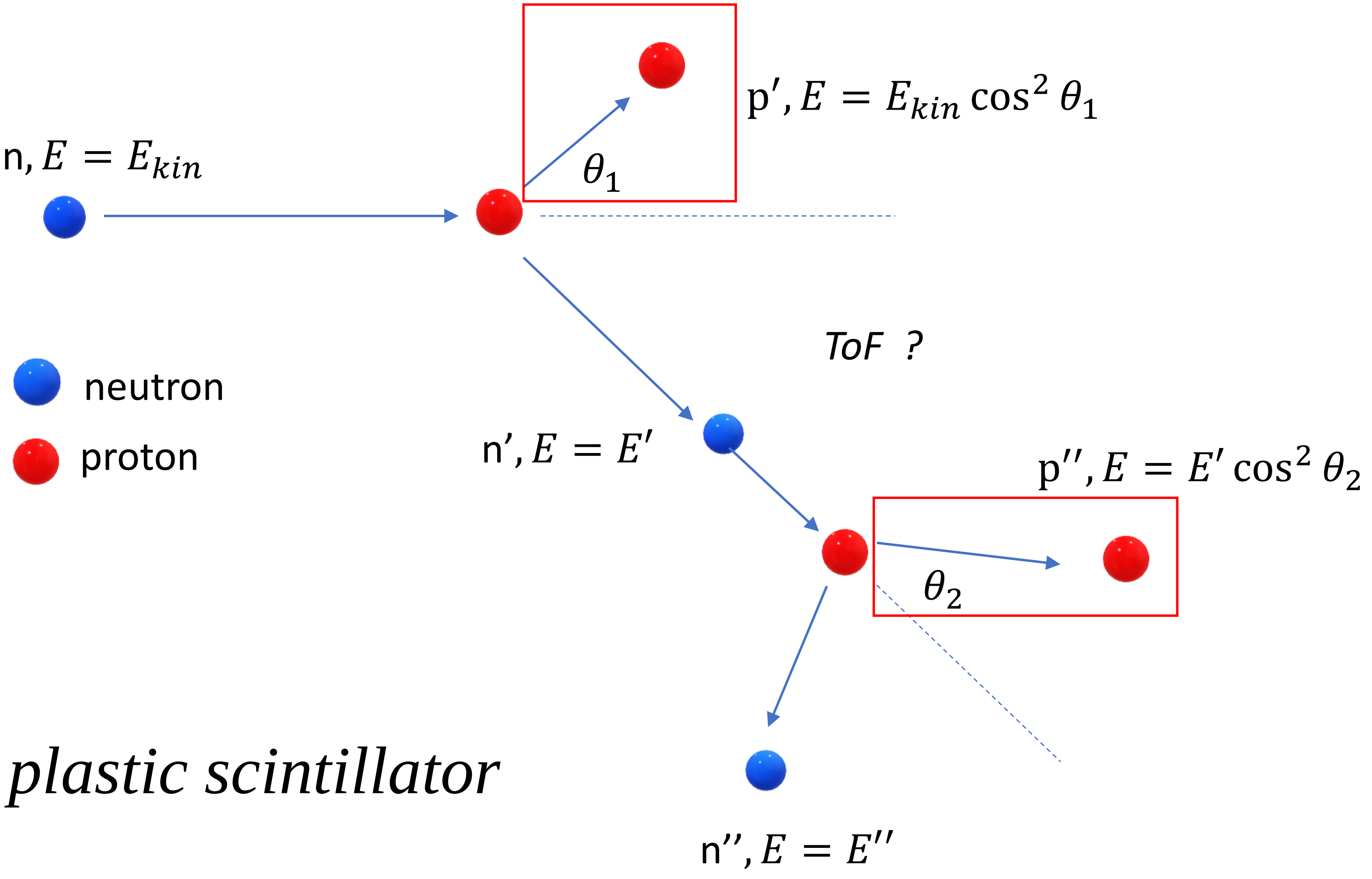
*DIRTY* and *NASTY*



**e**

J. Hu et al, Sci. Rep. 8, 13363 (2018)
M. Filipenko et al. Eur. Phys. J. C (2014) 74:3131

# *Recoil Proton Technique*



n, $E = E_{kin}$

p′, $E = E_{kin} \cos^2 \theta_1$

$\theta_1$

ToF ?

● neutron

● proton

n′, $E = E'$

p″, $E = E' \cos^2 \theta_2$

$\theta_2$

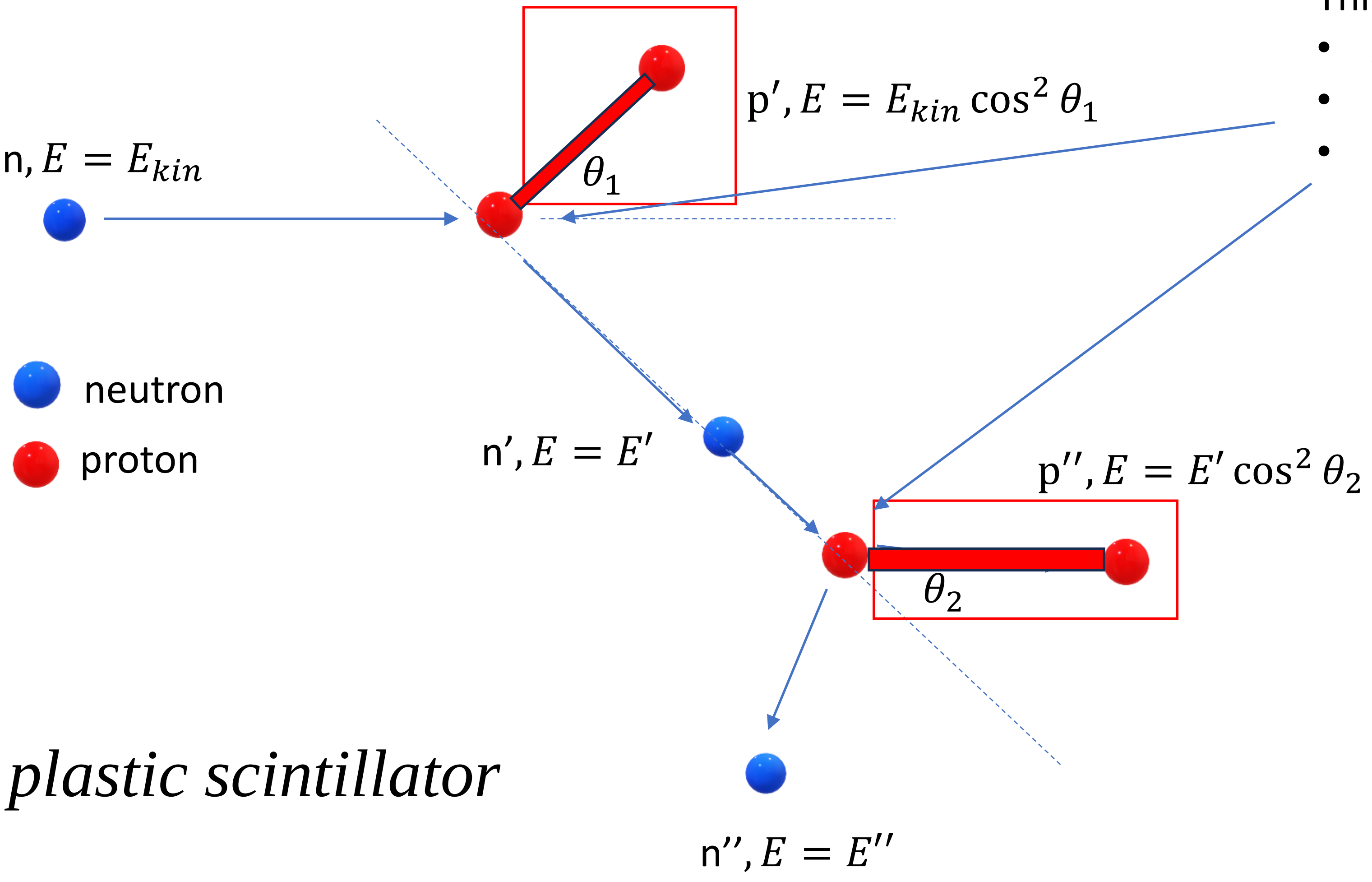
n″, $E = E''$

*In a plastic scintillator*

- If the neutron direction is known, the measurement of the recoiling proton energy (range) and direction can be used to deduce the incident neutron energy and direction (scattering plane and scattering angle can be determined)

- If incident neutron direction and energy are unknown double elastic scattering events can be used.

# *Recoil Proton Technique*



Three vertices
- *n*-source
- primary (first proton scattering)
- secondary (second proton scattering)

*In a plastic scintillator*

primary and secondary vertex
+ proton energy measured

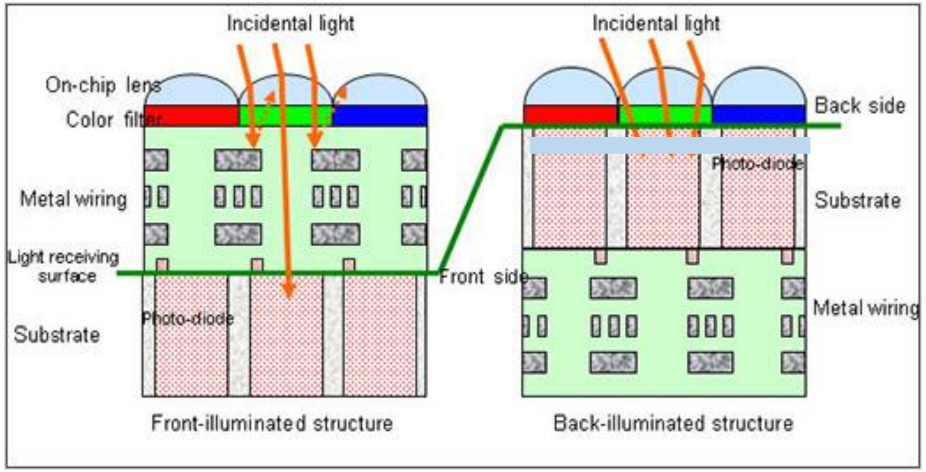
*n′* energy deduced

# *Option 1: High Sensitivity CMOS (INFN-CT)*

***CMOS camera***

Sony IMX294(mono)
4k x 2.8 k pixels
14 bits ADC, monochrome

**In progress@INFN-CT**



***Pros:***

Easy implementation

Benchmark for optics

Low power

***Cons:***

Low fps

No external correlation

# *Option 2: fast sensor and ASICs readout (INFN-BO)*

- TimePix 3.0

***Pros:***

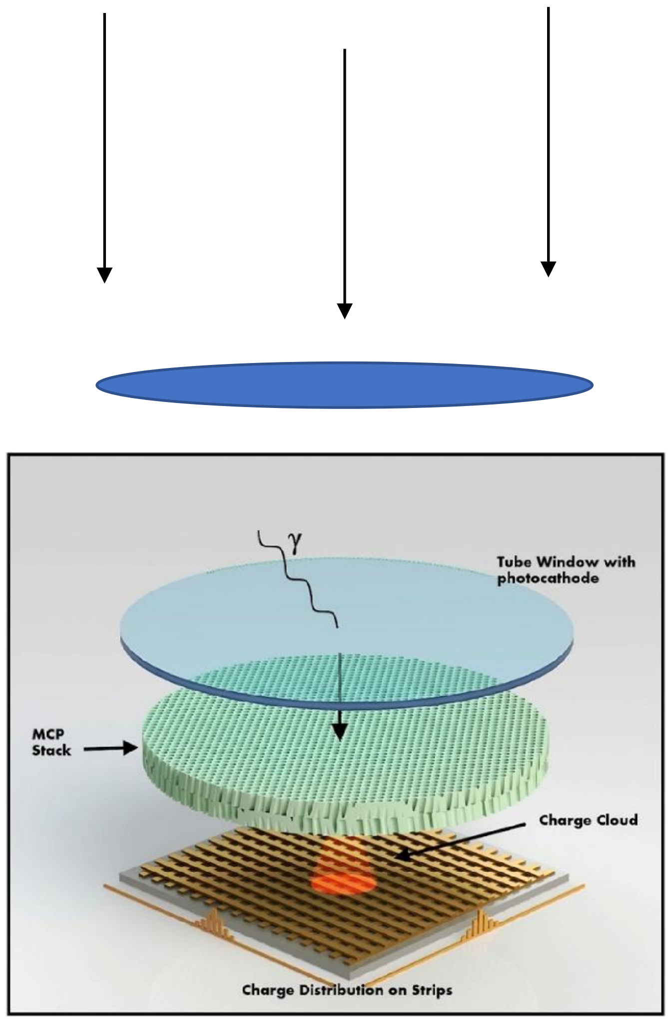
Real-time (1 ns response)

High rate ( >10 kHz )

Large surfaces (>1 cm$^2$)

***Cons:***

Complexity, cost



*Photons*

*Lens*

*Photocathode*

*MCP*

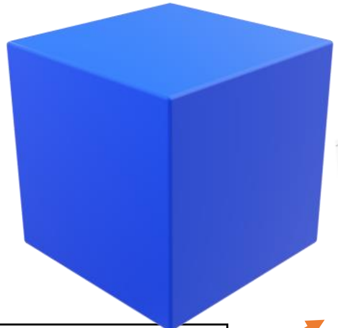
*TIMEPIX*

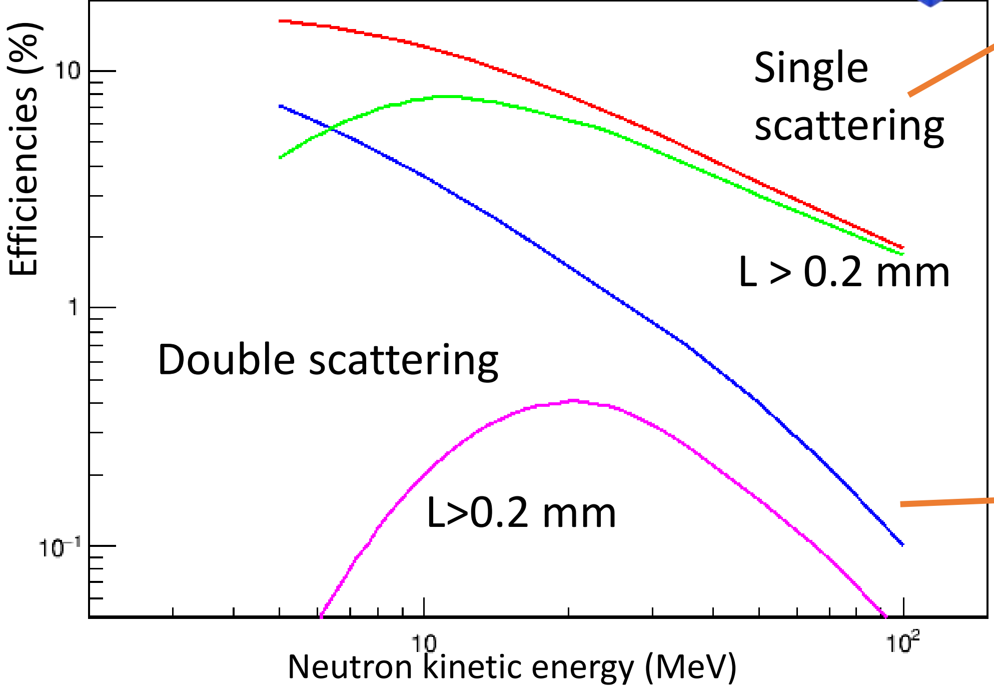
# Interactions and detection efficiencies (*proton track reconstruction*)

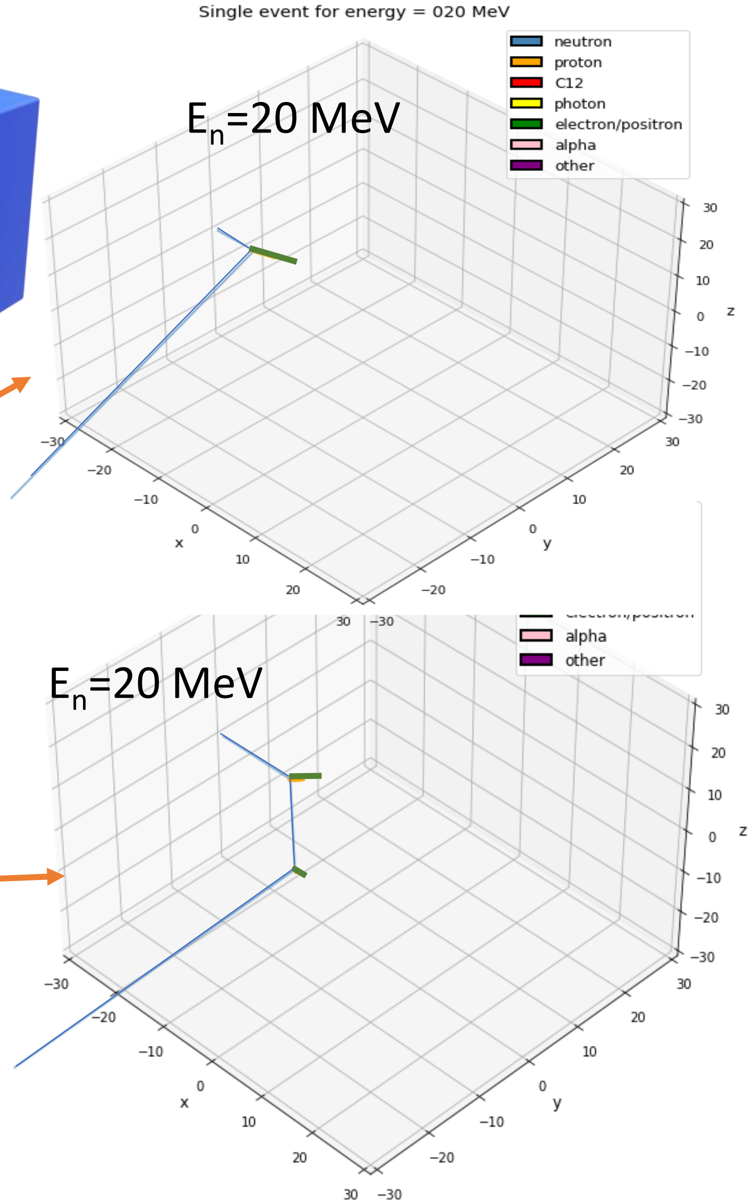
Detection volume: 6x6x6 cm$^3$

Neutron energies: 3-100 MeV

Proton ranges: 0.2 – 30 mm

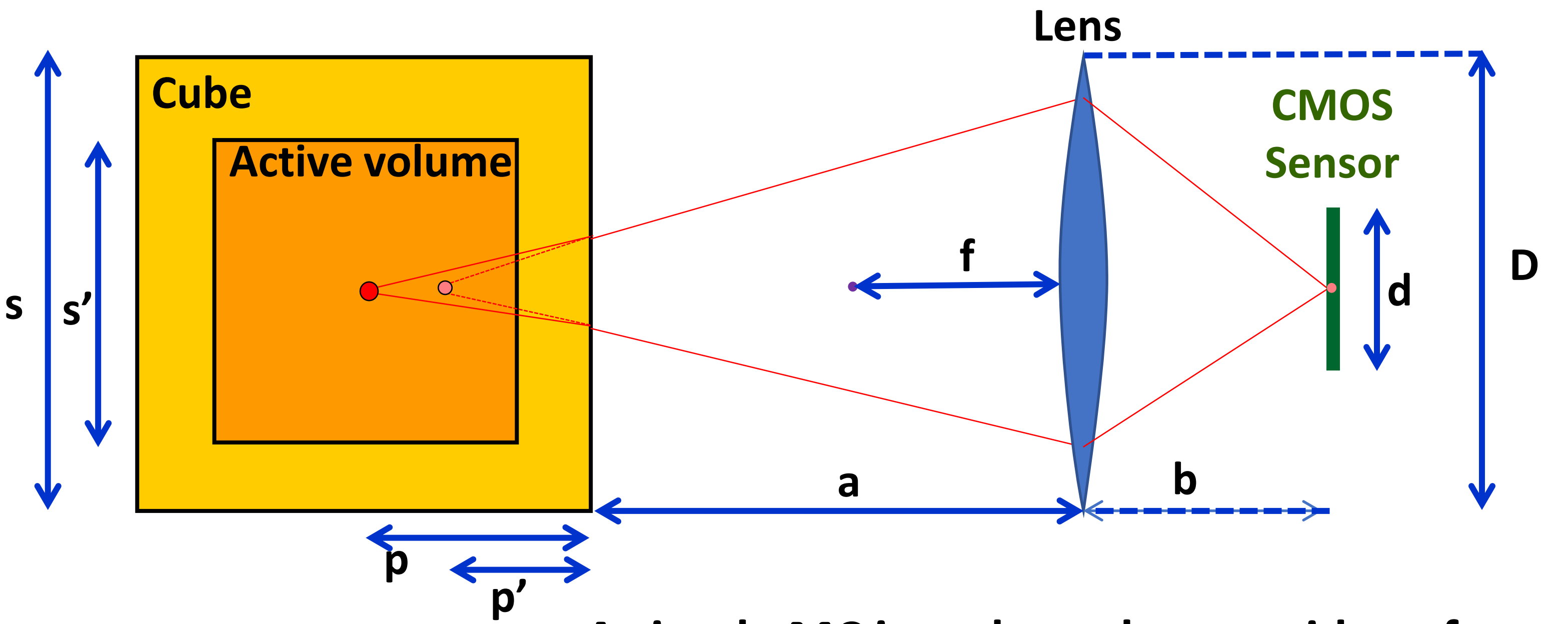






***Track reconstruction in progress (INFN-BO)***

# *Optics simulated by the INFN-Bo group*



**A simple MC in order to have an idea of the image size and overall performances**

| Parameter | values |
|---|---|
| s: scintillator size | 60 mm |
| s’: side of the active cube | 40 mm |
| d: side of the CCD sensor | 20 mm |
| f: focal length of the lens | 30 mm f = D/2 |
| D: diameter of the lens | 60 mm |
| a: position of the lens | 71 mm a = p’’ – p’ |
| b: position of the sensor | 45 mm b = fp’’/(p’’-f) |

*Main problems:*

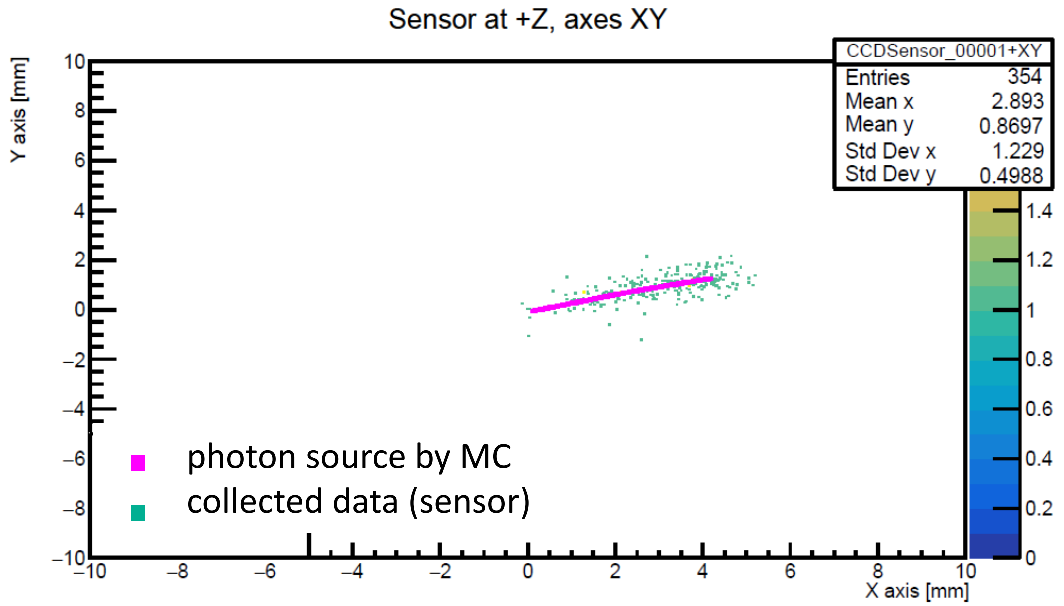
- aberrations
- field of view
- depth of field

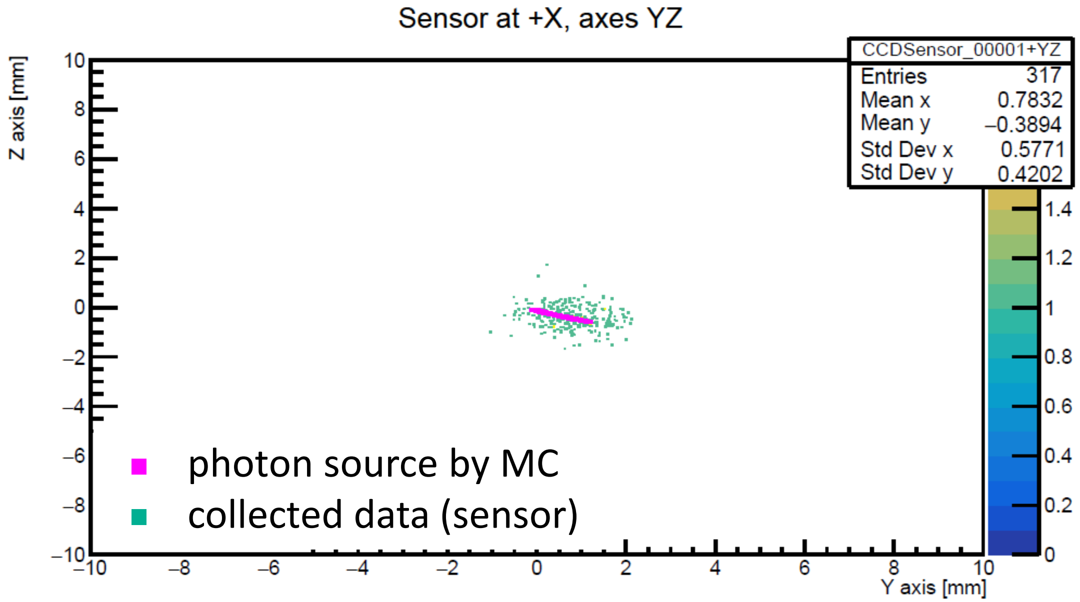
↓

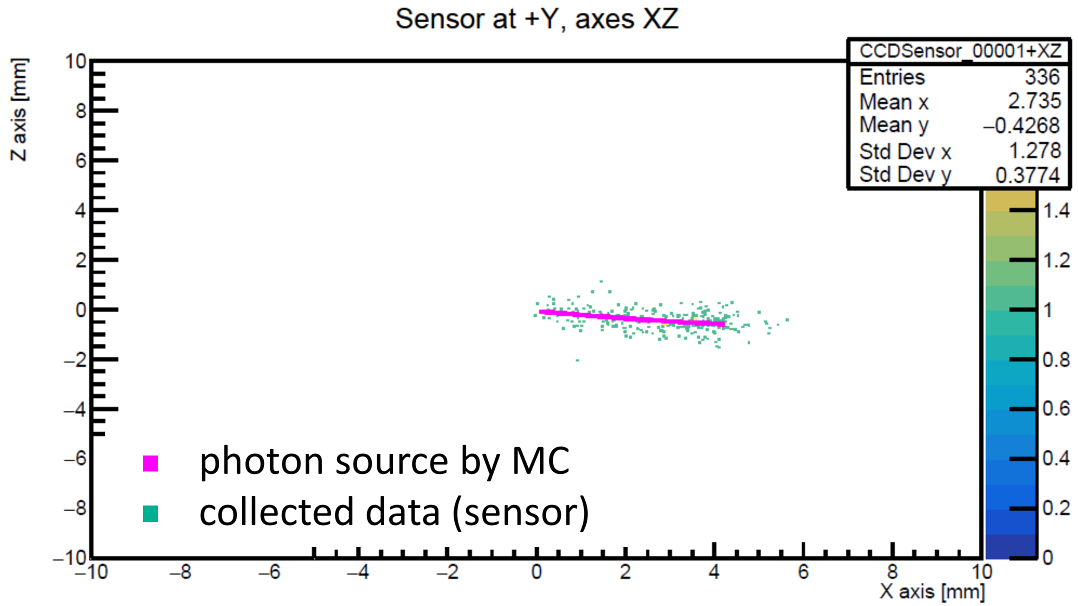
small active volume

# *PCA analysis 30 MeV proton track* *By Patrizio*

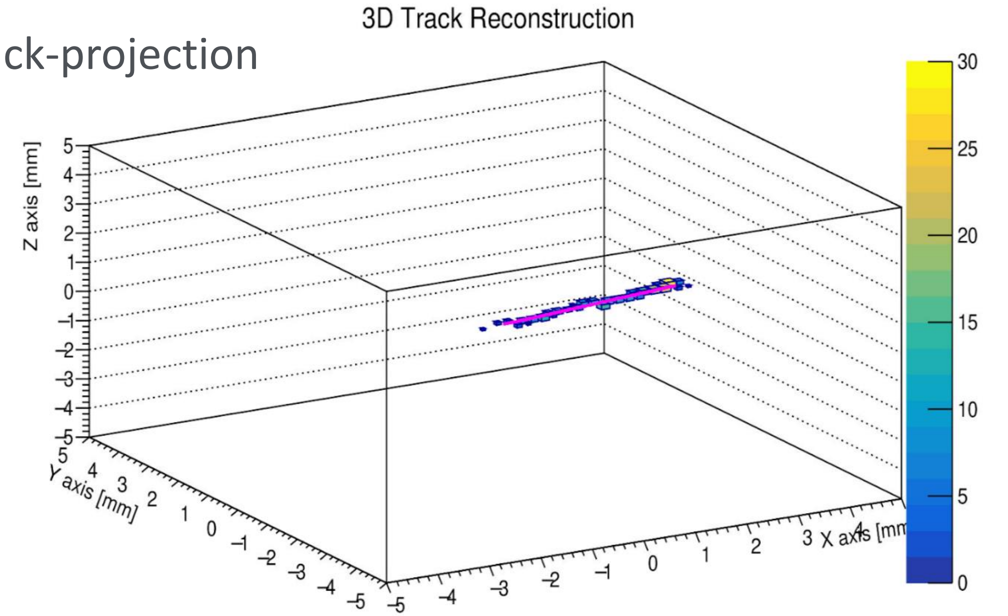
*more than a simple regression problem*


Sensor at +Z, axes XY


Sensor at +X, axes YZ


Sensor at +Y, axes XZ

Back-projection


3D Track Reconstruction

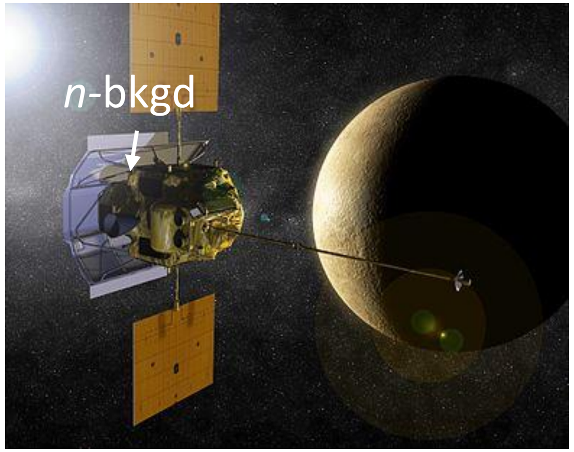
# Application: solar neutrons detection in space

Space exploration is the only method to detect neutrons (En<100MeV), while spacecraft and ground-based detectors can detect neutrons (En>100MeV) simultaneously

Neutron-dominated enhancements are always connected with the observable flares, while the solar origin of proton-dominated enhancement often concentrates at the western heliolongitudes

Sept. 10, 2017, X8.2-class solar flare

*n*



***MESSENGER** (**ME**rcury **S**urface, **S**pace **EN** vironment, **GE**ochemistry and **R**anging)*

*BepiColombo*