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

(RecoIl ProTon Imaging DEtector)

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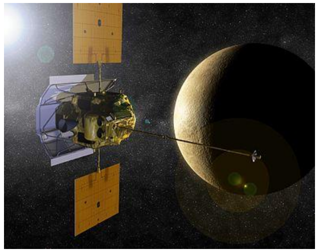
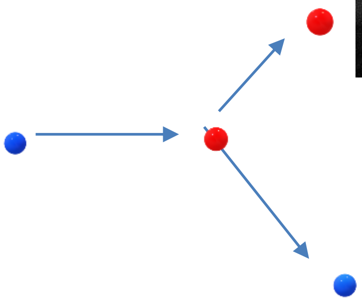
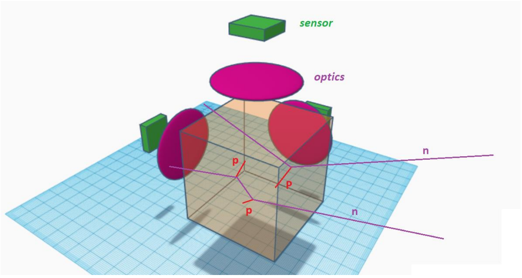
Outline

- Context
- Neutron tracking
- Proton recoil technique
- Detector basic principles
- Sensor chips
- Efficiencies
- Electronics
- Summary







Context: measurement of neutron direction and energy

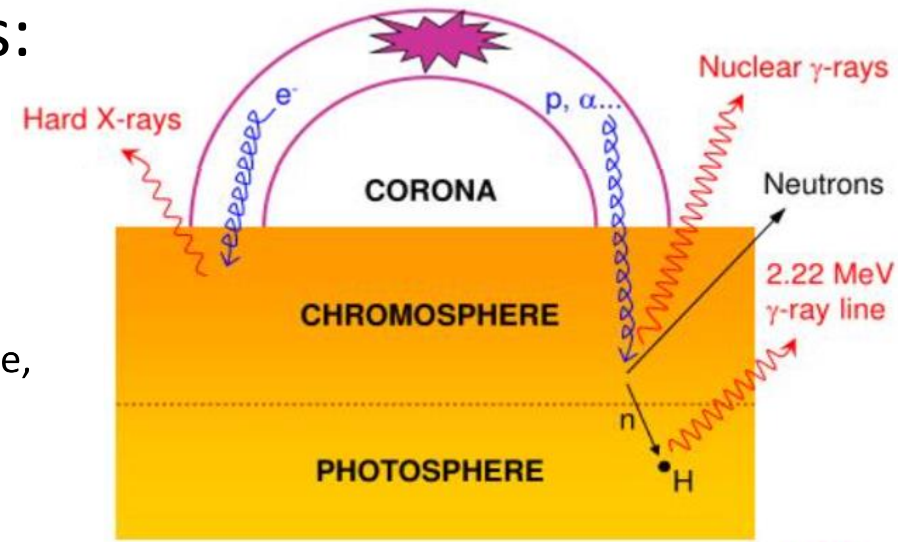
- Several researches would benefit of neutron track direction and energy measurements
- Neutrons are produced in a variety of environments, yet their «tracking» is difficult due to the way they intectact
- Break-up: e.g. $n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79\ MeV$
- Absorption: e.g. $n + {}^{157}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum
- Elastic scattering $n + p \rightarrow n + p$
- Inelastic scattering $n + {}^{12}C \rightarrow n + 3\alpha$

Example 1: solar neutrons

Neutron production processes:

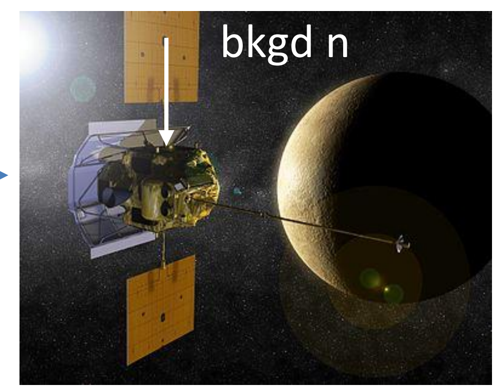
neutrons @E<30MeV are produced by
→heavy ions interaction on ambient H and ^{4}He

neutrons @ E>30MeV are predominately produced
→alpha-particle interactions with ambient H and ^{4}He,
→proton interactions with ambient ^{4}He
→*Only these can be detected near Earth*



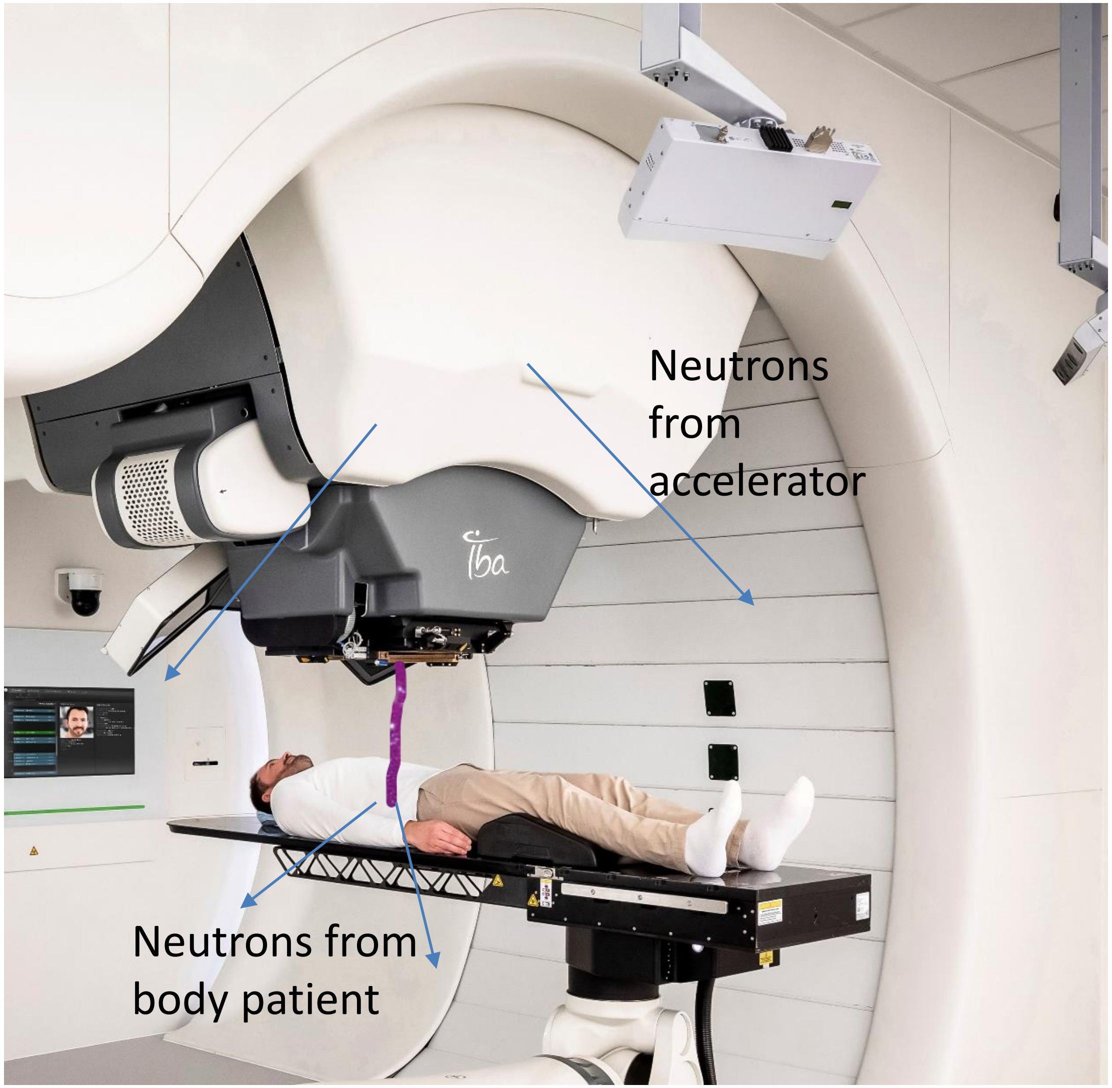
Gross, Kiener, Tatischeff

n



Messanger probe

Example 2: hadrontherapy



Neutrons are produced

- In the accelerator head
- In the body patient

  $p+^{16}O \rightarrow n+p+^{15}O$

Neutron track direction

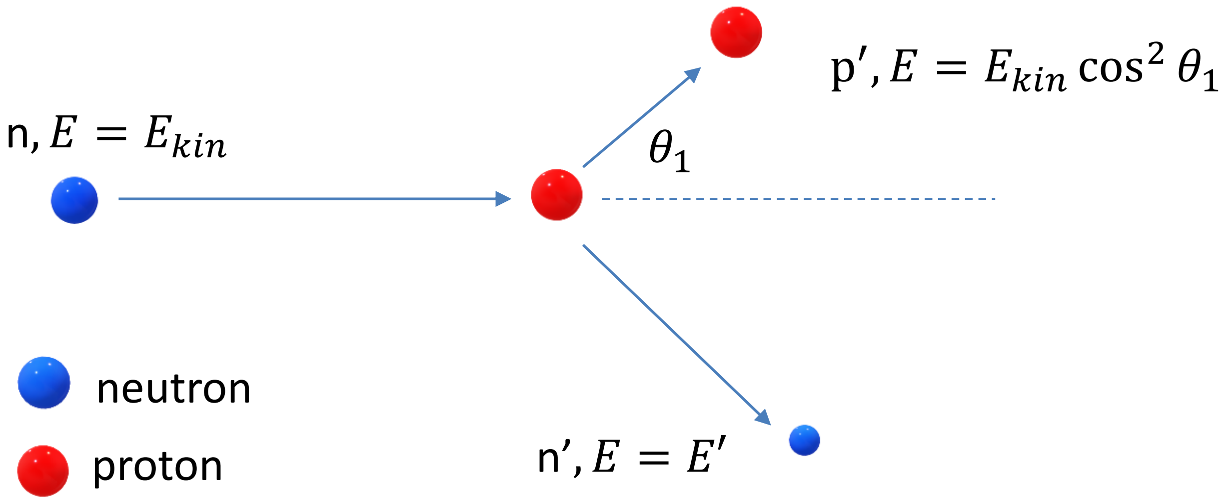
Is needed to distinguish between the two contributions

Measurements needed to:

- improve the TPS
- estimate the secondary production

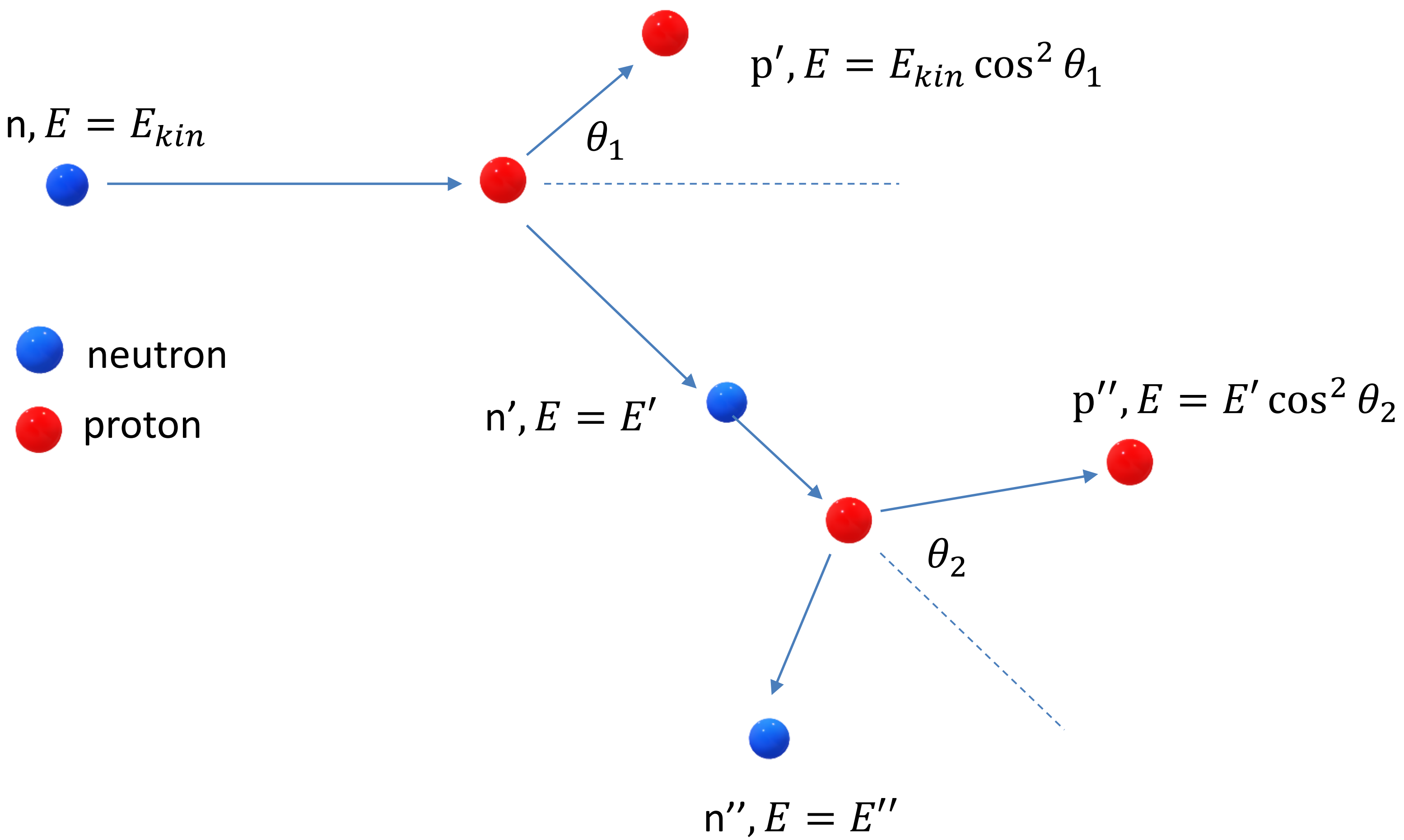
Can be used to monitor the beam in the patient

Recoil Proton Technique



In a highly hydrogenated material

Recoil Proton Technique



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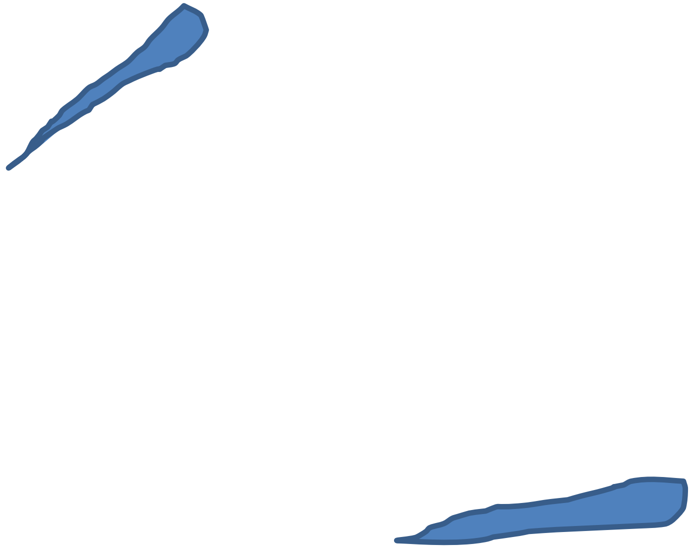
Recoil Proton Technique



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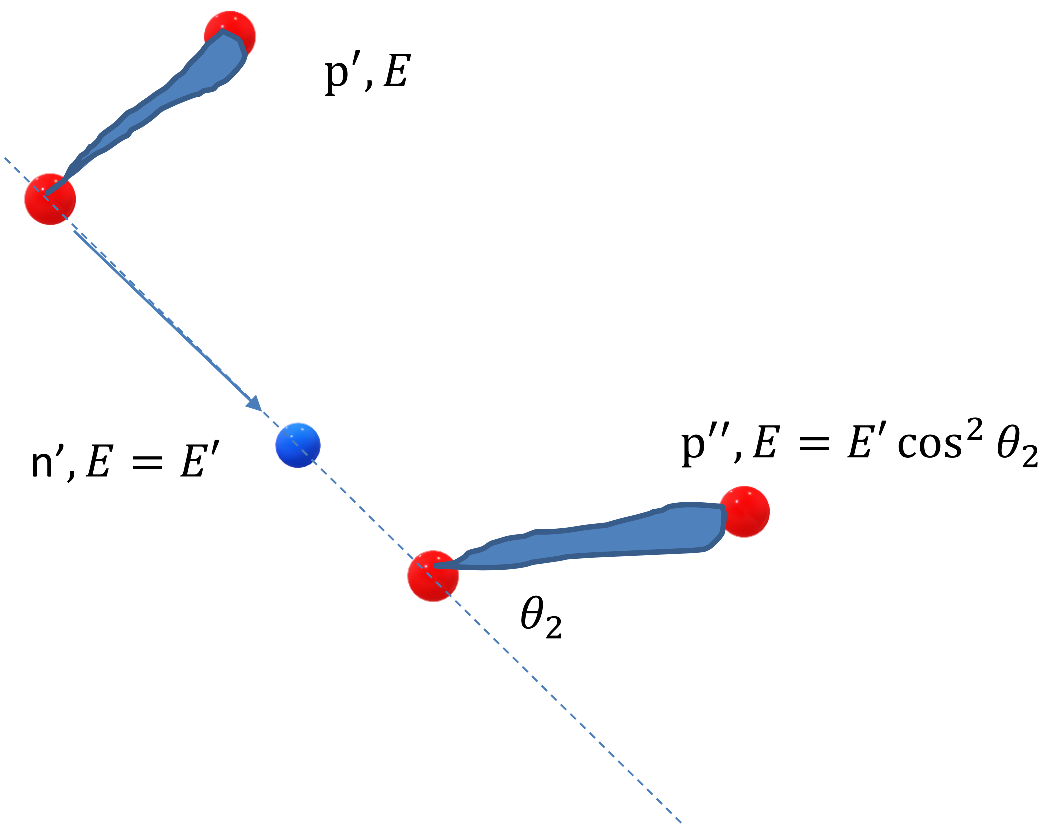
Recoil Proton Technique



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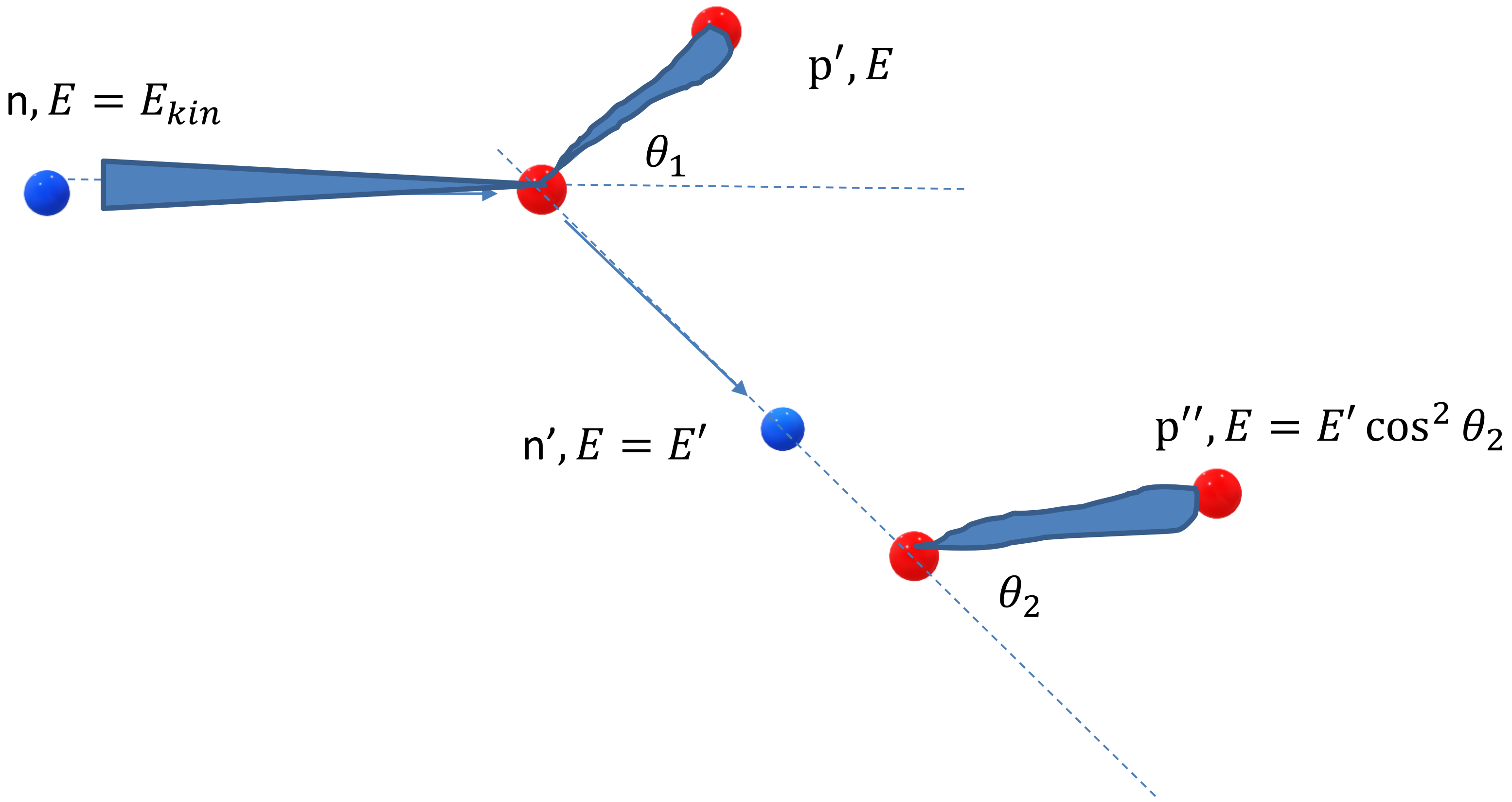
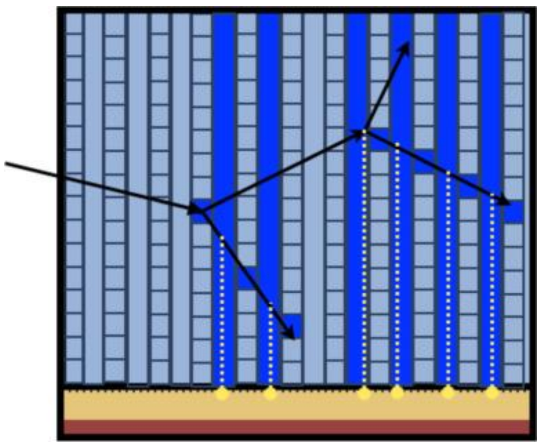
Recoil Proton Technique



In a highly hydrogenated material

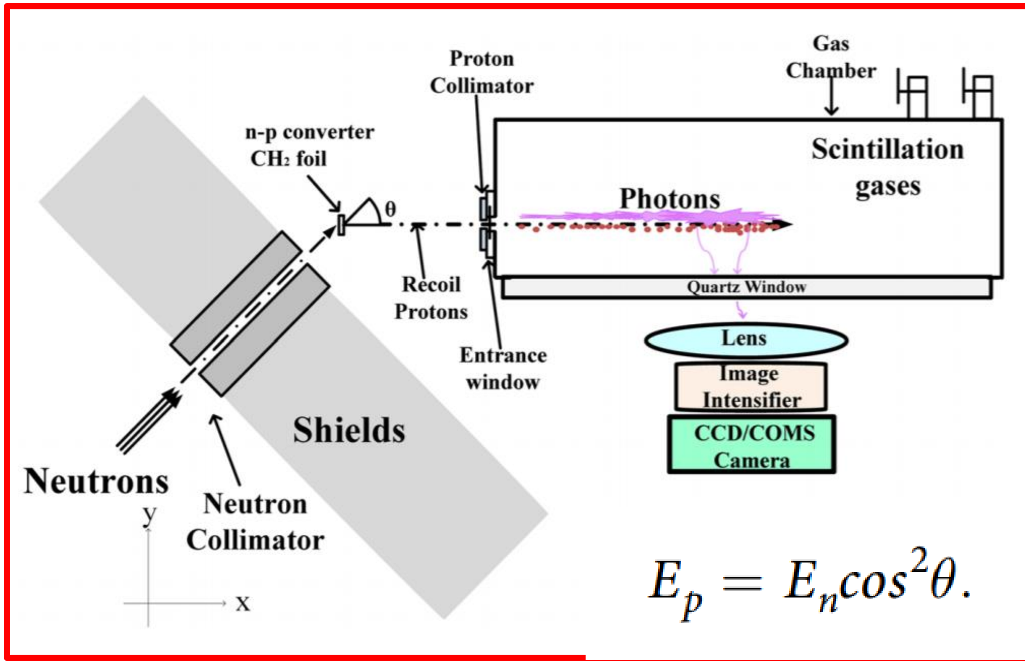
Existing projects (selection)

The MONDO project
(scintillating fibers)



NIM A 845 (2017) 556

(see also SONTRAC)



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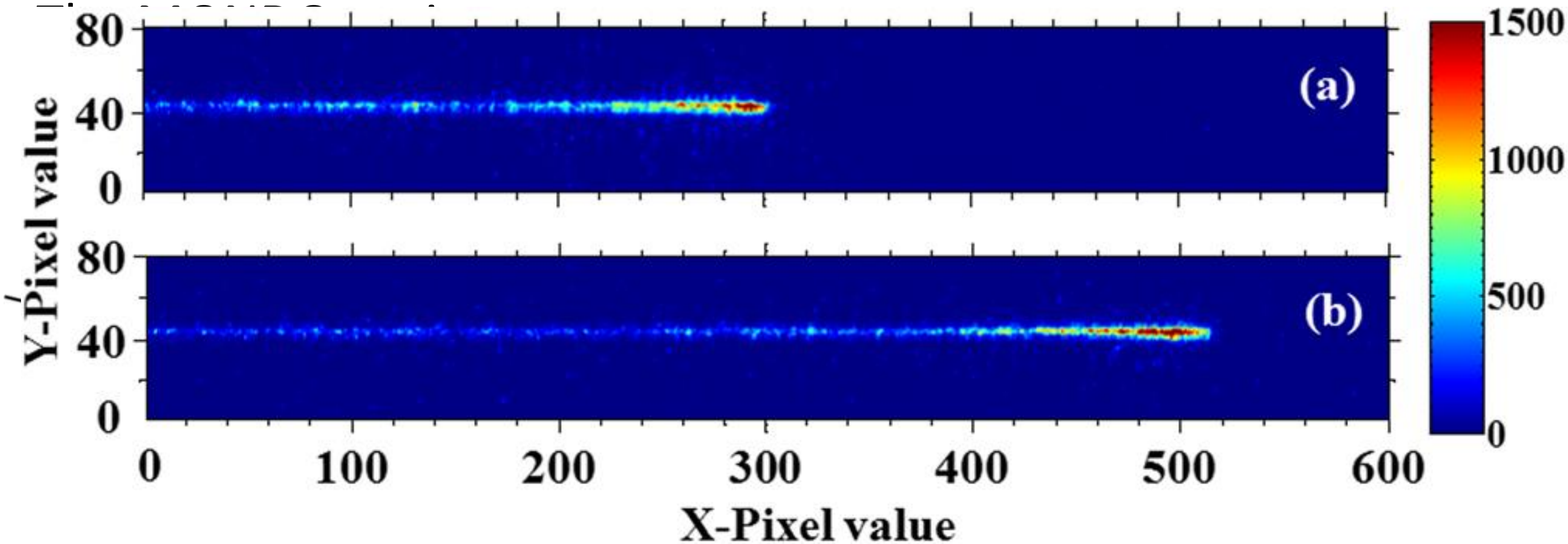

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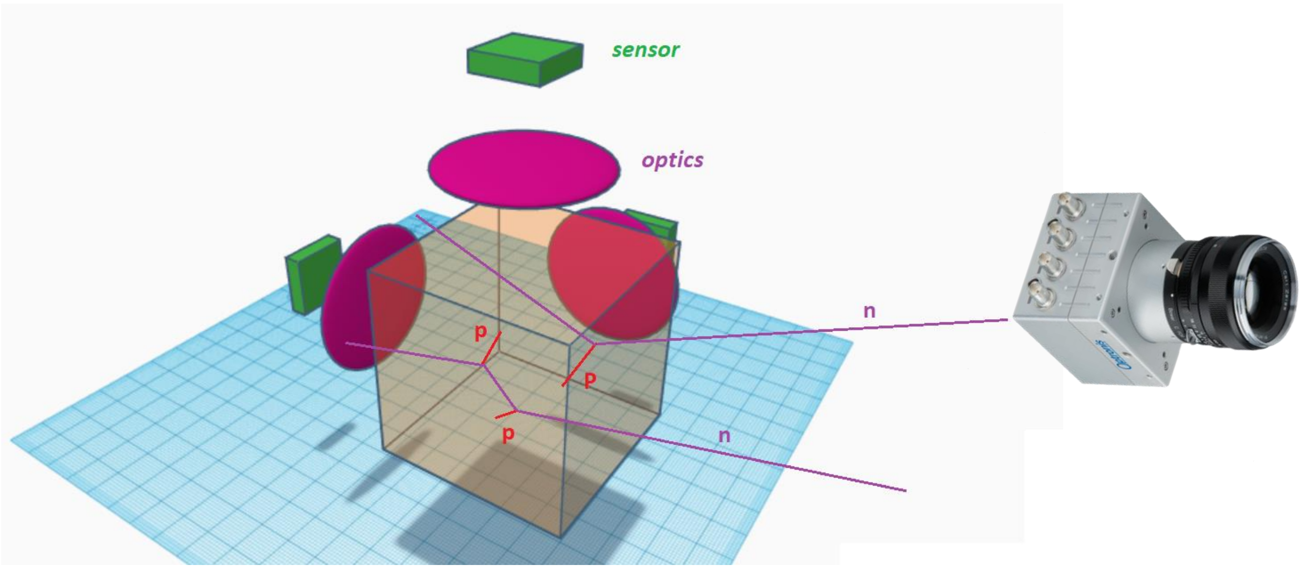
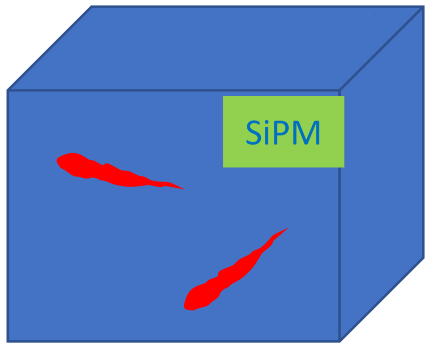
(see also SONTRAC)

RIPTIDE detector concept

- A cube of plastic scintillator (L=6 cm)
- Seen by 3 fast image sensors
- Seen by one or more SiPM





Double scattering needed when neutron source is not known
Single scattering when source position is known
Time-of-flight can be used for the neutron energy measurement

Sensor option 1: CCD

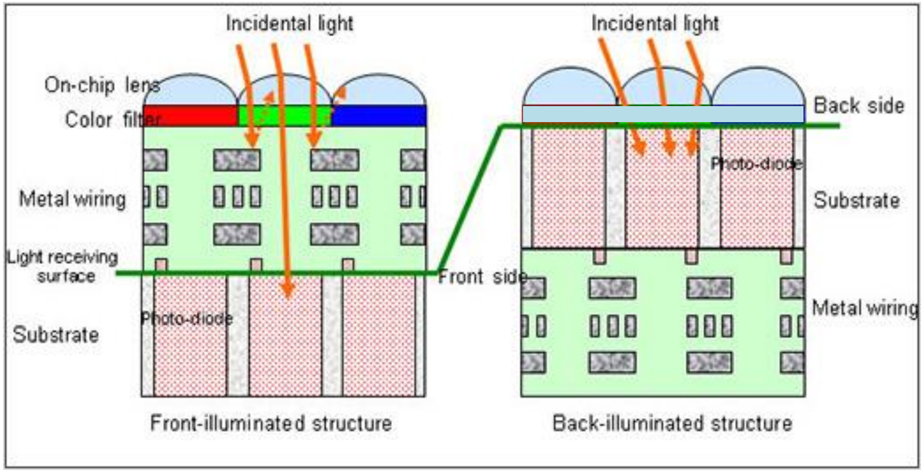
Commercial CMOS CCD

Sony IMX492 (IMX327)

16 fps (60 fps)

4k x 2.8 k pixels

14 bits adc, monochrome



Pro:

On the shelf! And in our lab!

Direct connection with a PC

Cont:

Low fps

No empty pixel suppression

High dead time during reading

Sensor option 2: special ASICs

- Mimosa M28 (ultimate)
- TimePix 3 …
- Other ….

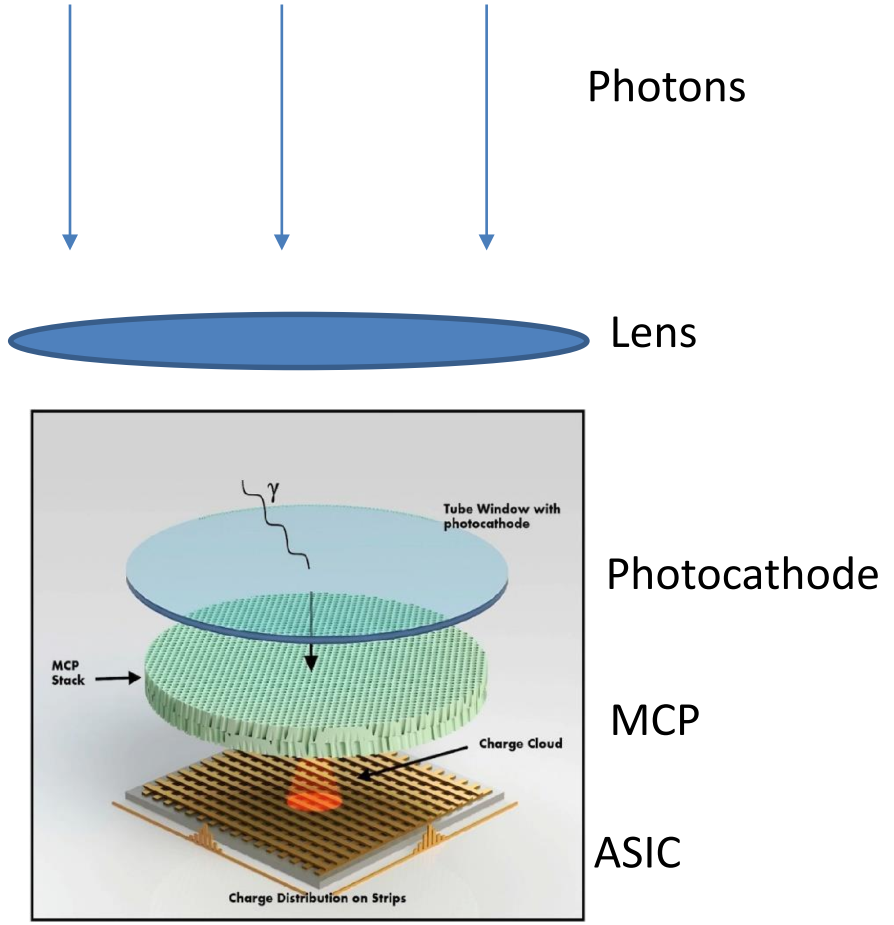
Pro:

Zero suppression

Rolling shutter (almost no dead time)

High fps (>5 kHz)

Large surfaces (>1 cm^2)



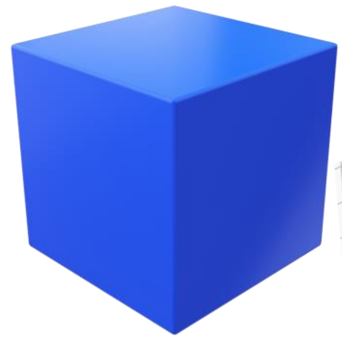
Assembly to be developed

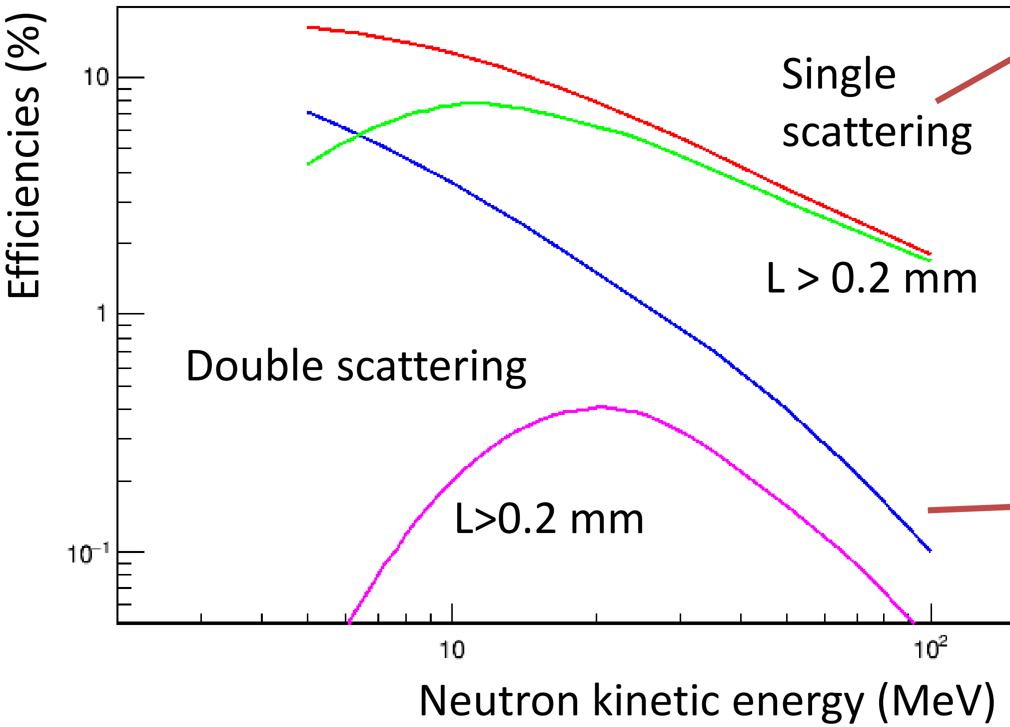
Interactions and detection efficiencies

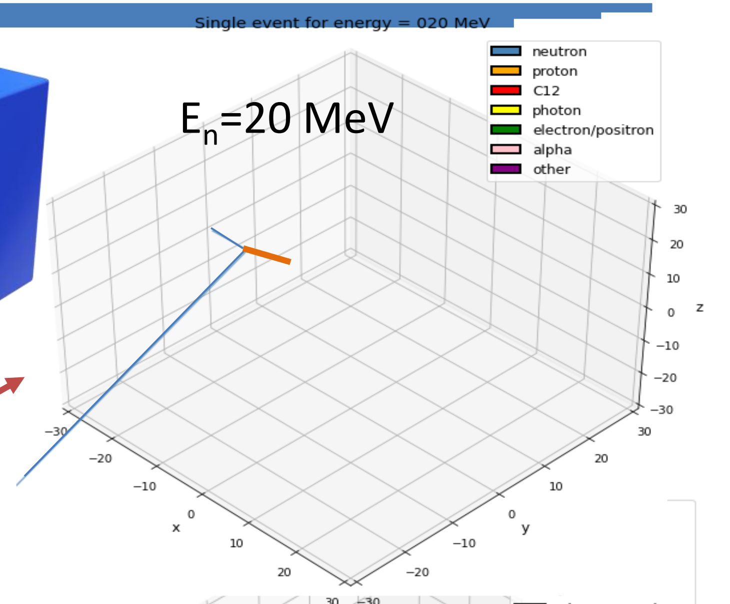
Detection volume: $(6\ cm)^3$

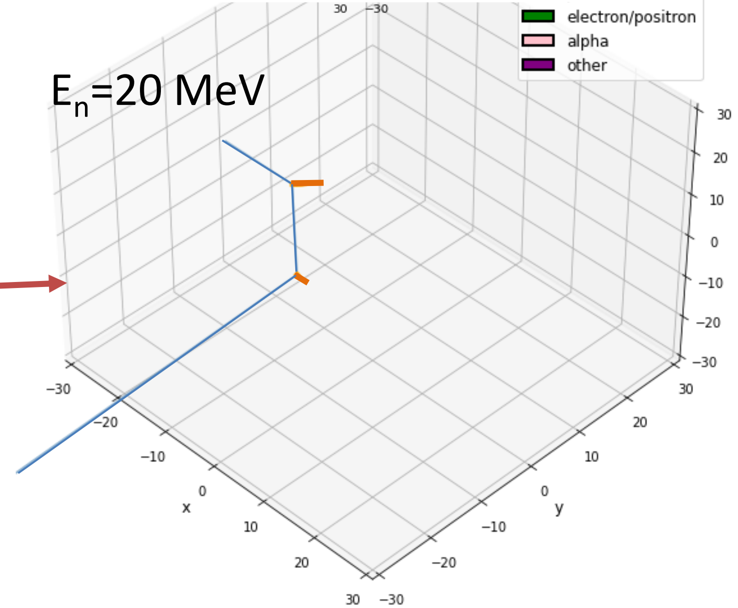
Neutron energies: 3-100 MeV

Proton ranges: 0.2 - 30 mm





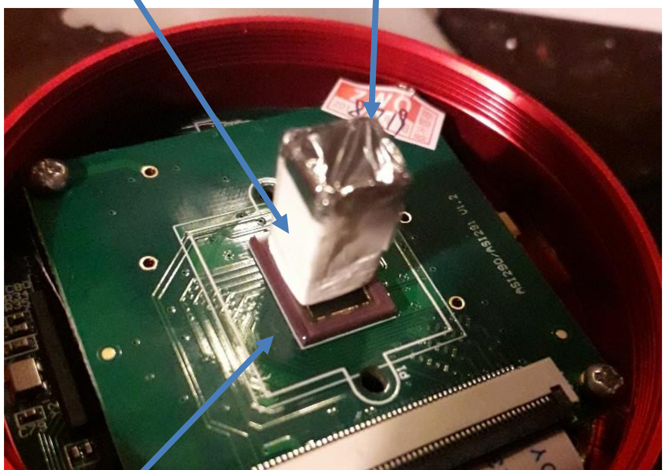




Ongoing tests

- Scintillator test

Neutron source (^{241}Am)

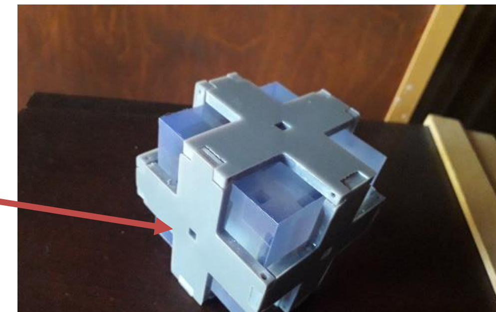


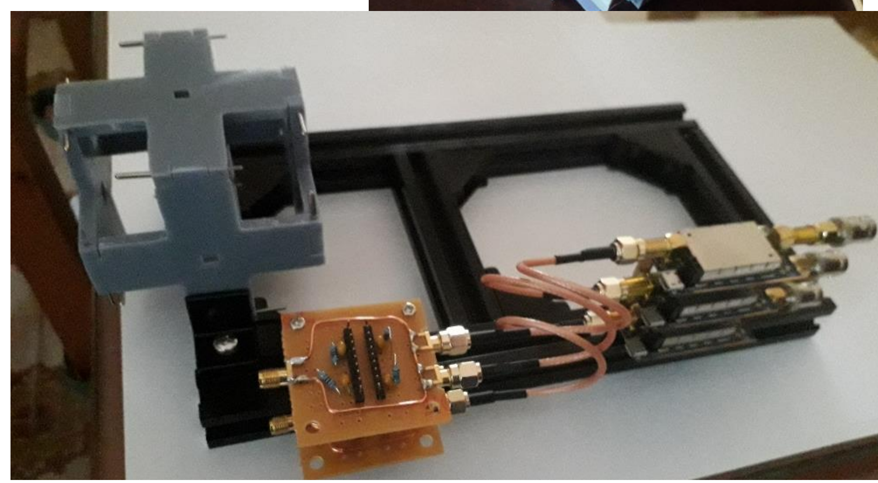
Commercial sensor

Scintillator characterization in progress

- Cube test

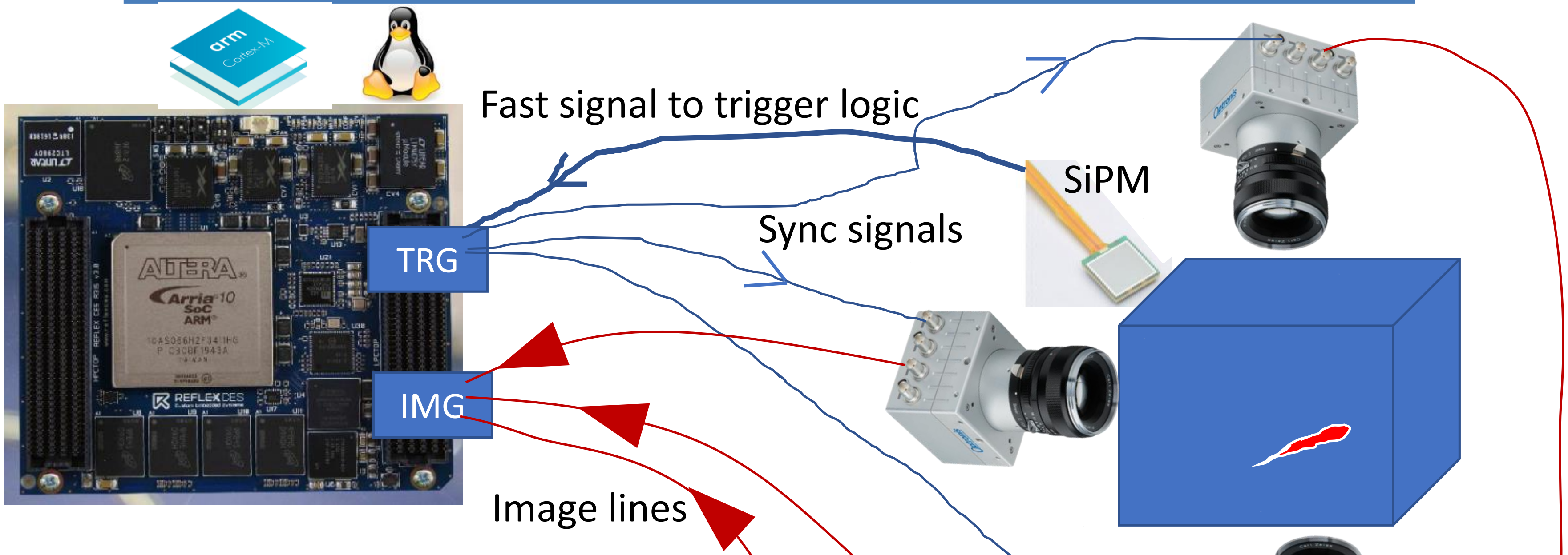
SiPM locations





To be tested at CERN in July
With SiPM and a commercial CCD camera

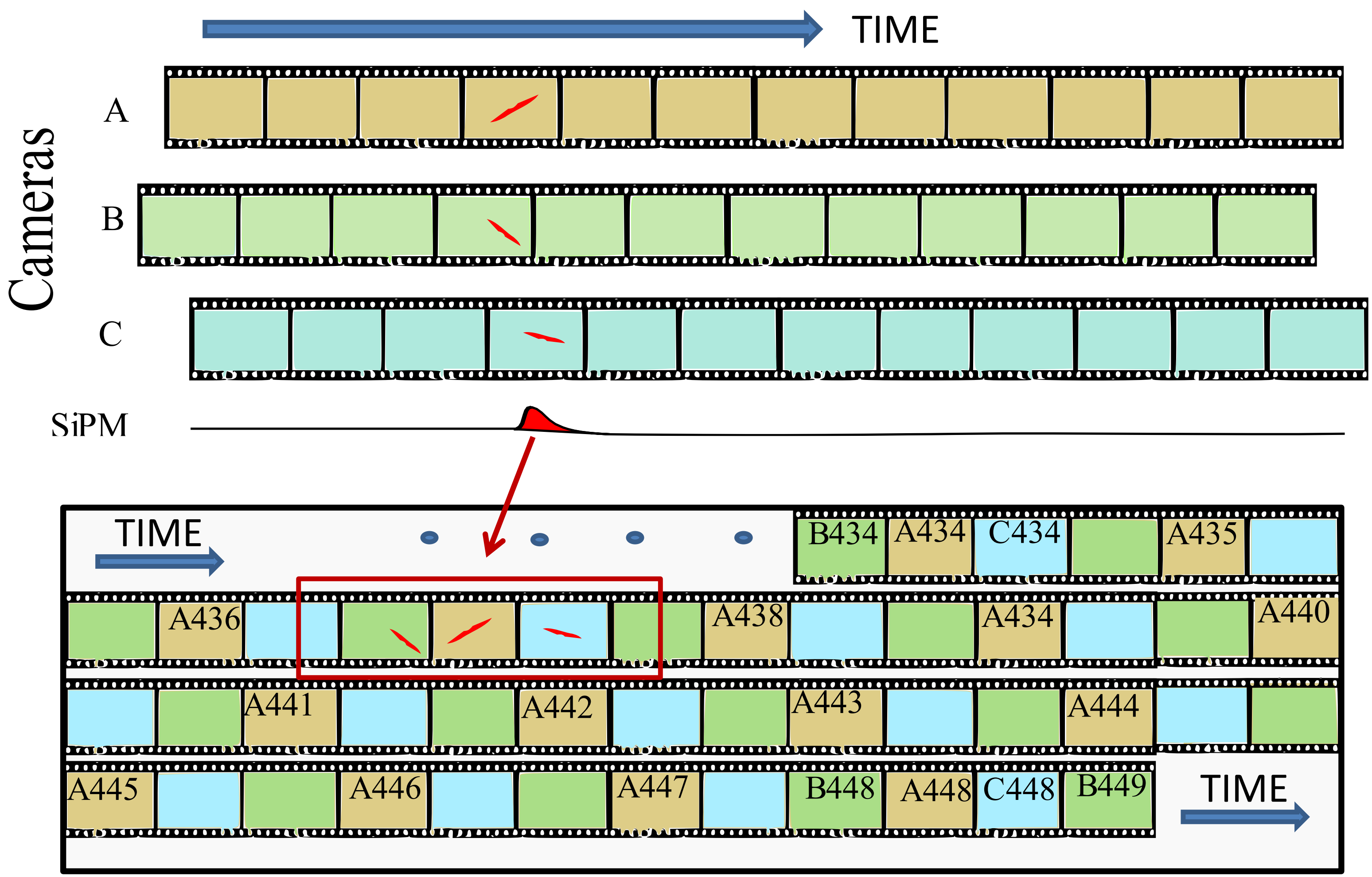
Data collecting electronics



Duties:

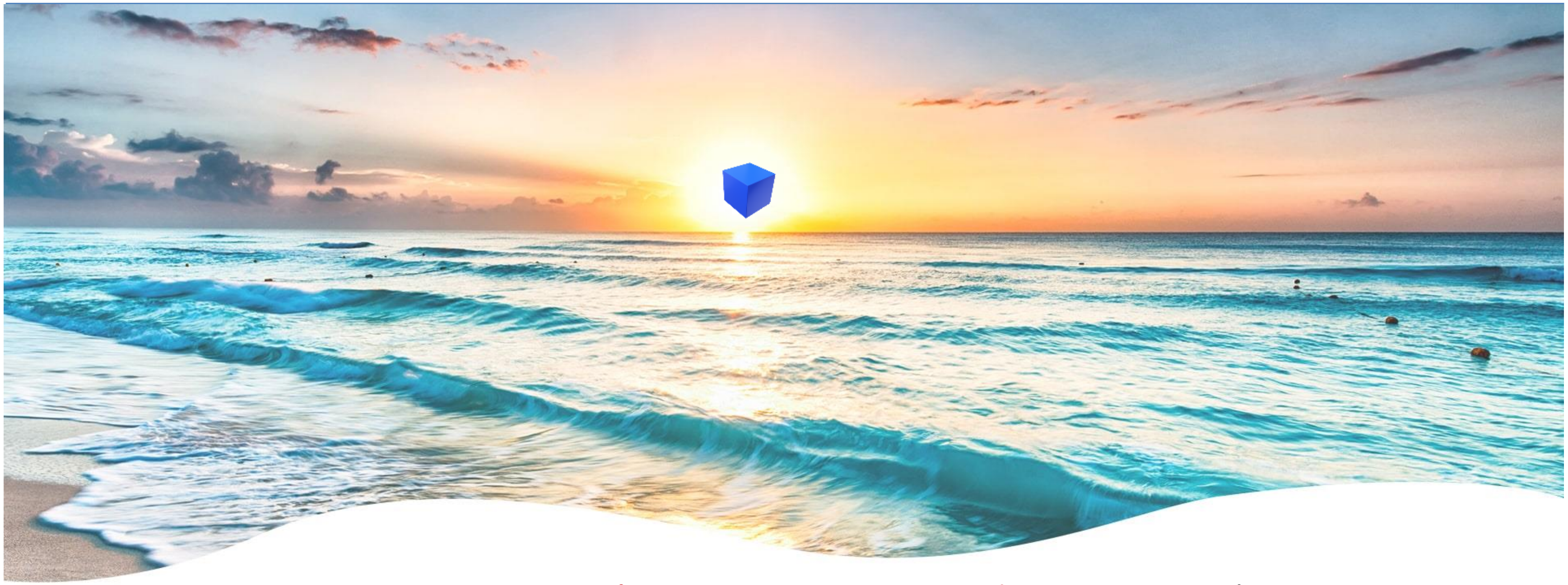
Provide synchronization signals
Identify interesting events (external trigger)
Process 3 images on the fly and correlate them
Store images with scattered protons
Measure energy (easy, ADC sums, cluster size)
and start & stop points (not so easy) → Use of FPGA+CPU SoC assembly

Sorting and triggering



Circular buffer of time-sorted images

Conclusions



- A new **neutron tracking imaging detector** has been described: RIPTIDE
- MC studies and lab tests are ongoing
- Detection efficiencies > 10 % @ 10 MeV (single scat.)
- Realization is under way

Thanks for the attention

Essential Bibliography

- Riptide: A. Musumarra et al, JINST 16 (2021) C12013-5
- Mondo: S.M. Valle et al, NIM A 845 (2017) 556
- Recoil proton: J. Hu et al, Sci. Rep. 8 (2018) 13363
- SONTRAC: G. A. De Nolfo et al, PoS 36 (2019) 1074
- N tracking: Z Wang, C Morris, NIM A 726 (2013) 145

Example 3: environment radiation

- Dosimeters: bonner sphere

- They provide neutron yield (with limited energy information) but no source information
- Neutron energy and direction can help in finding the source of (high energy) neutrons!