Development of imaging techniques for scintillating light tracks in a novel neutron detector

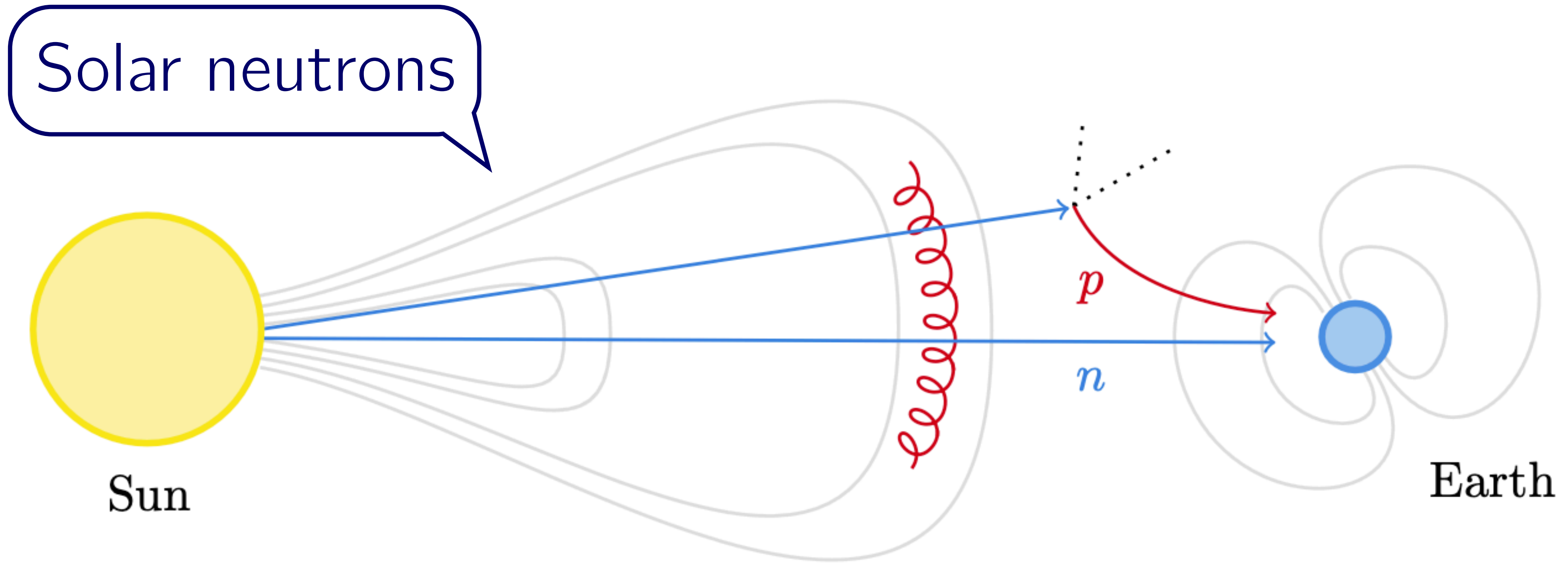
Samuele Lanzi   Licia Mozzina

22 November 2024

Motivations for neutron tracking

Neutron **trackers** are essential tools for the development of many research fields

Motivations for neutron tracking



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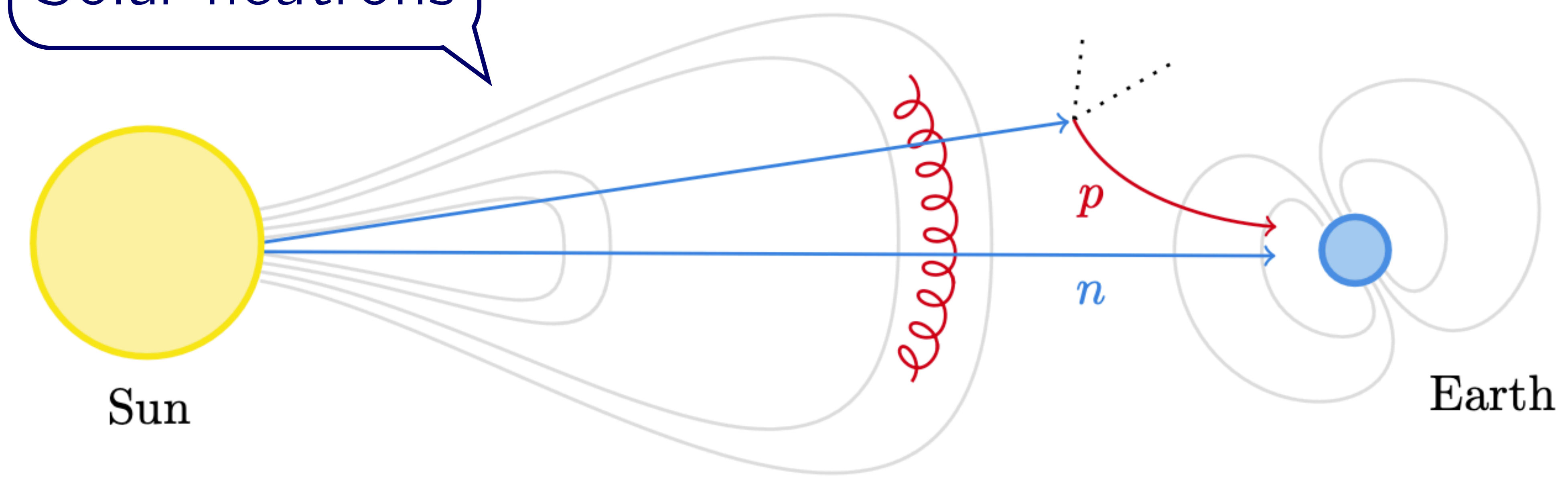
Motivations for neutron tracking

Solar neutrons



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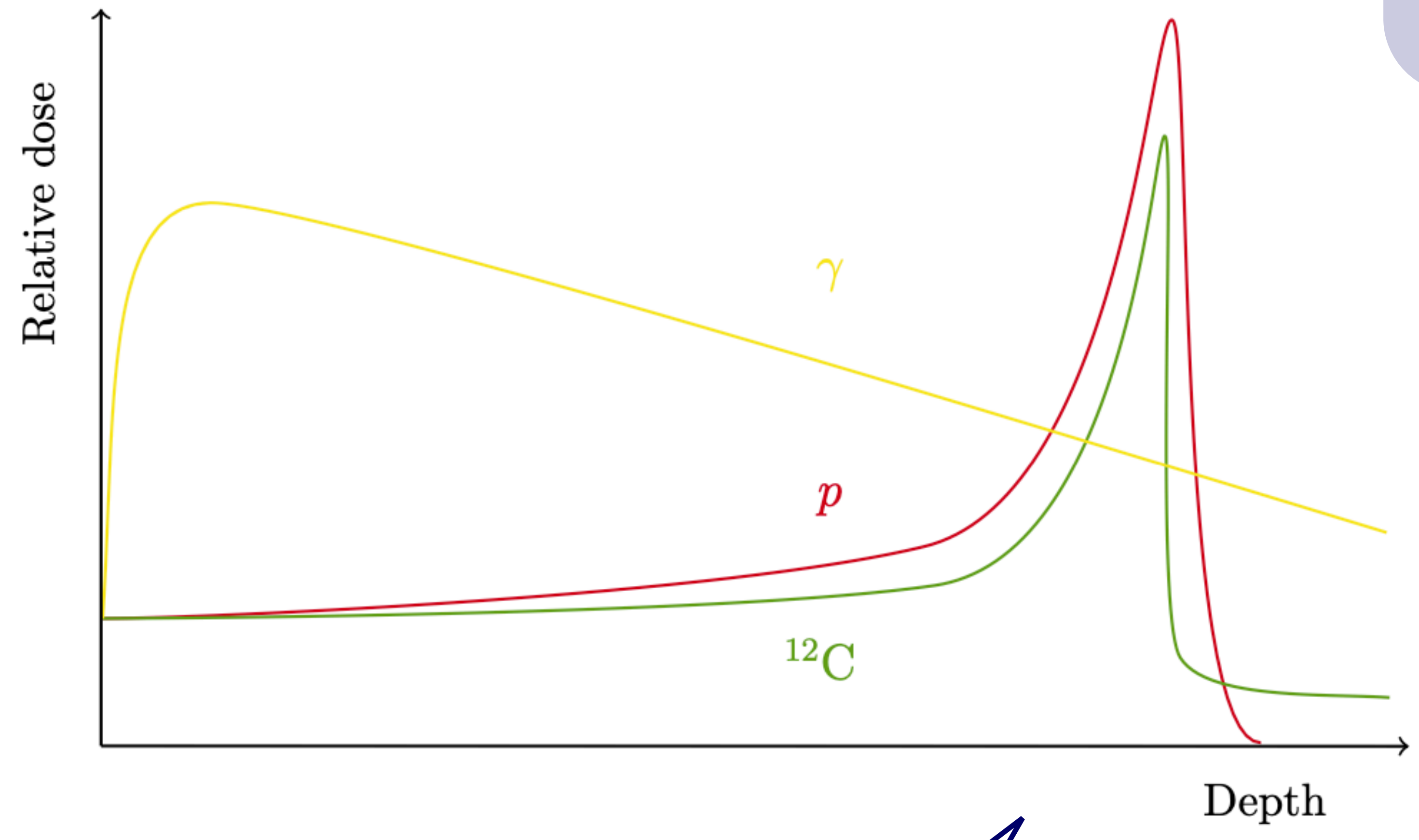

Hadrontherapy

Motivations for neutron tracking

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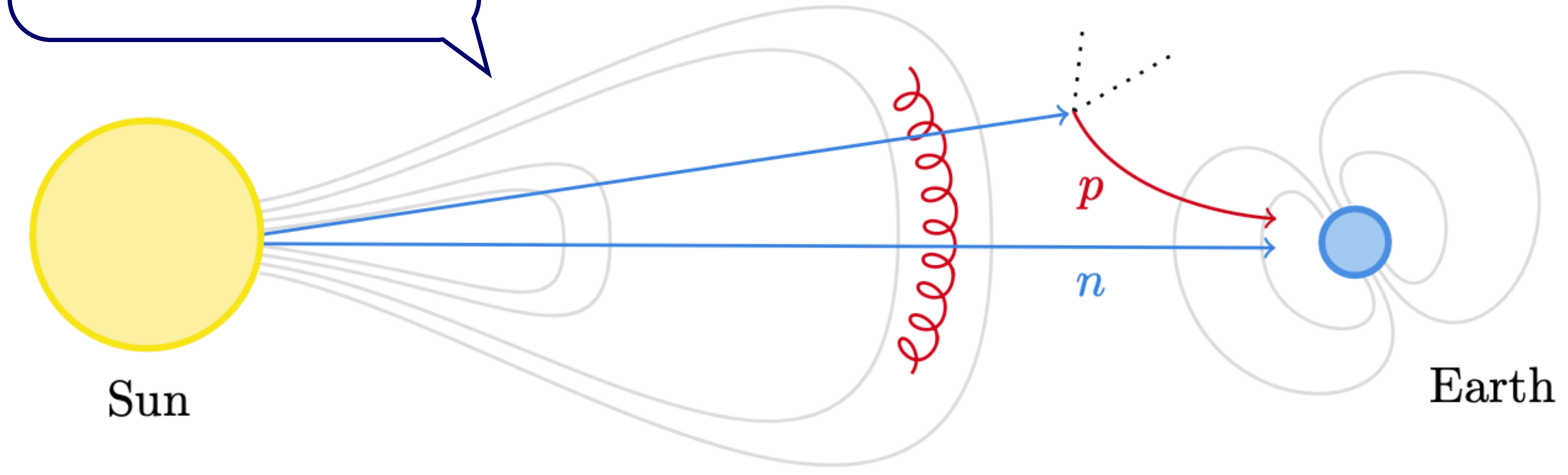
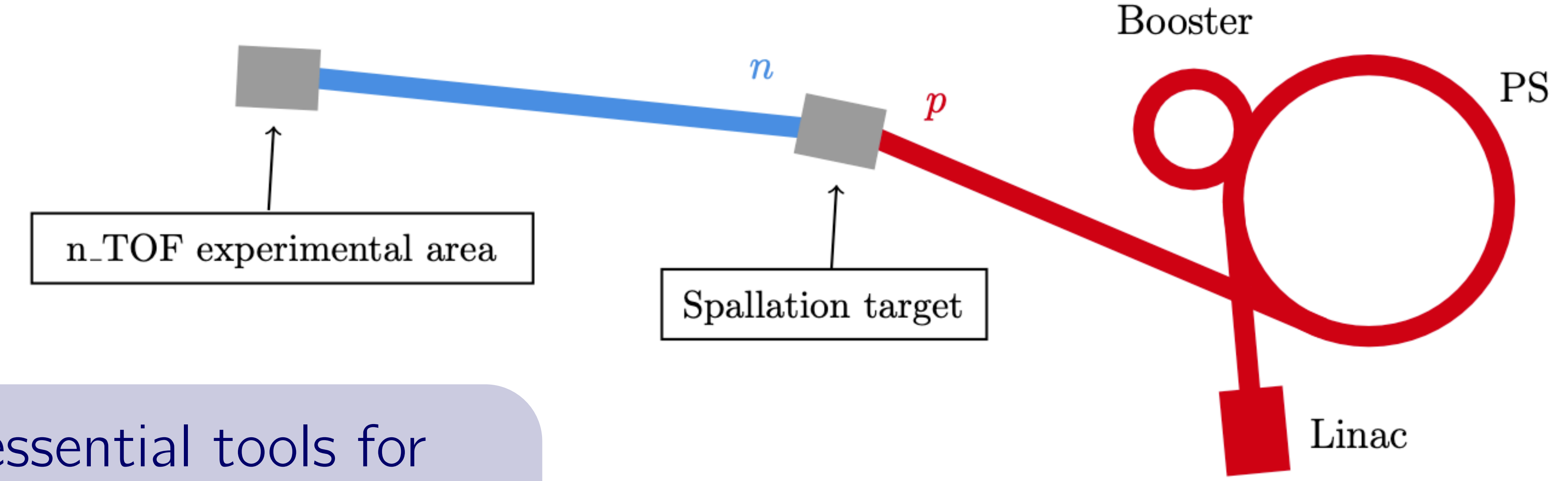


Nuclear physics



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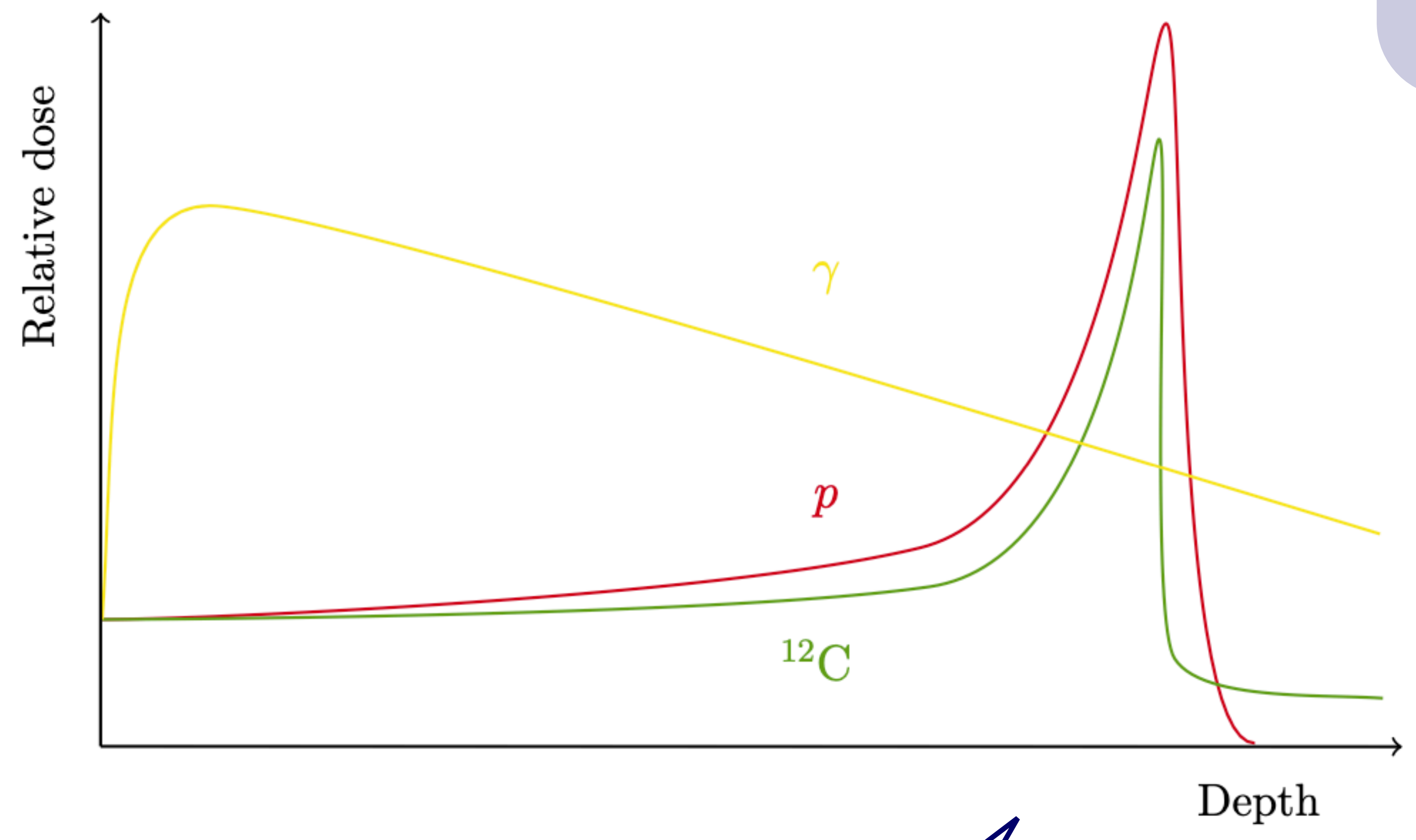

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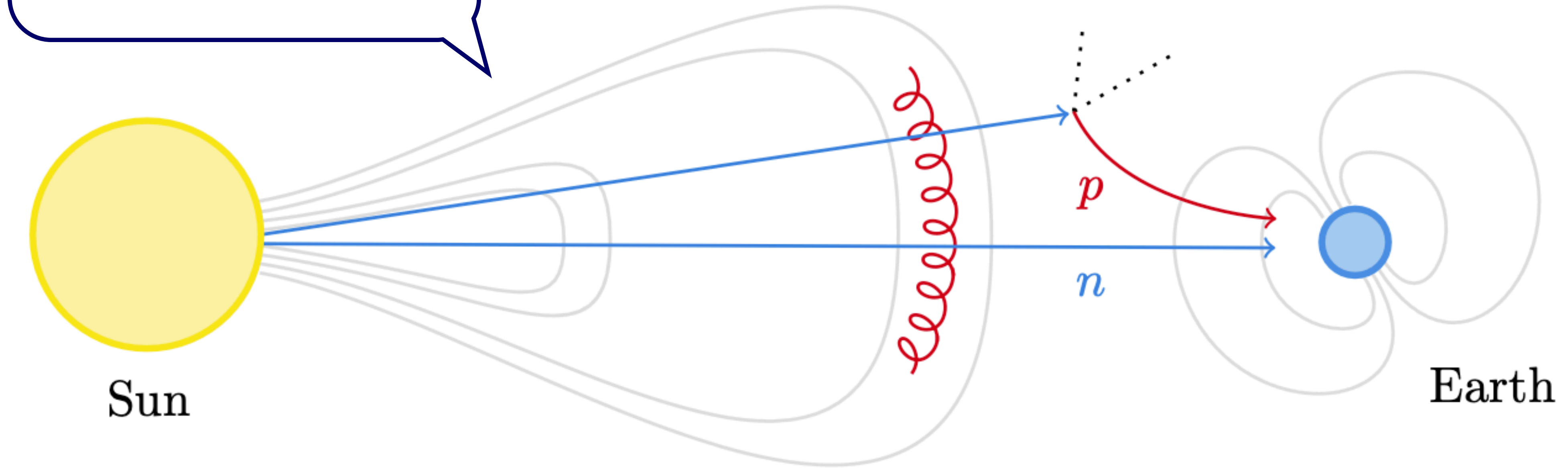

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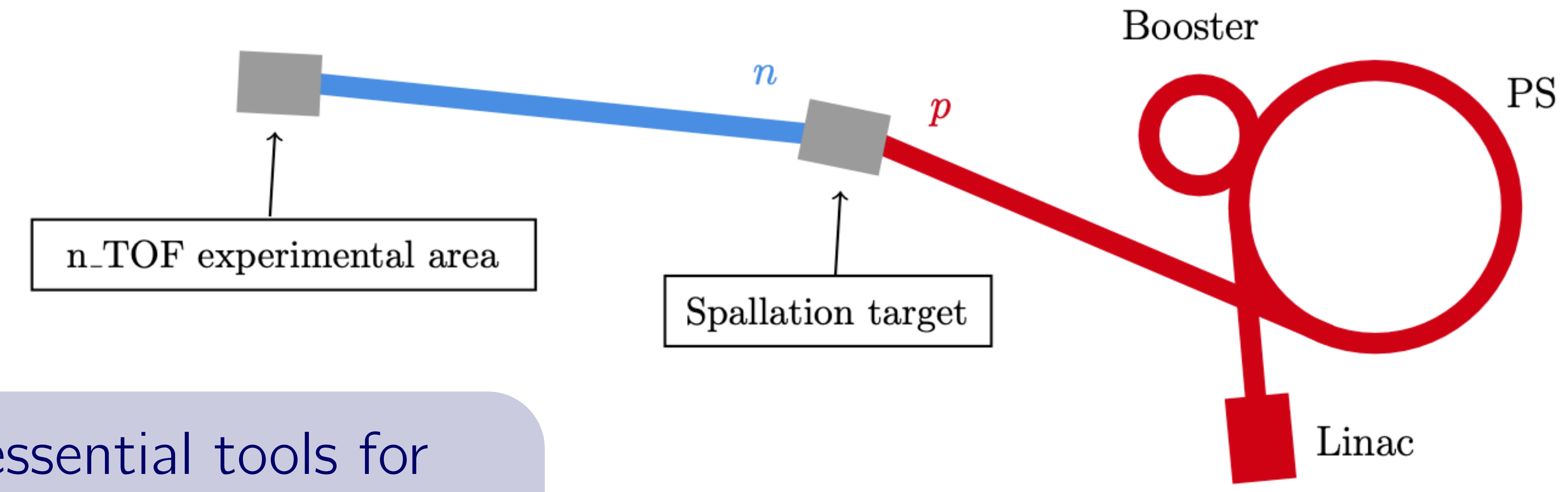

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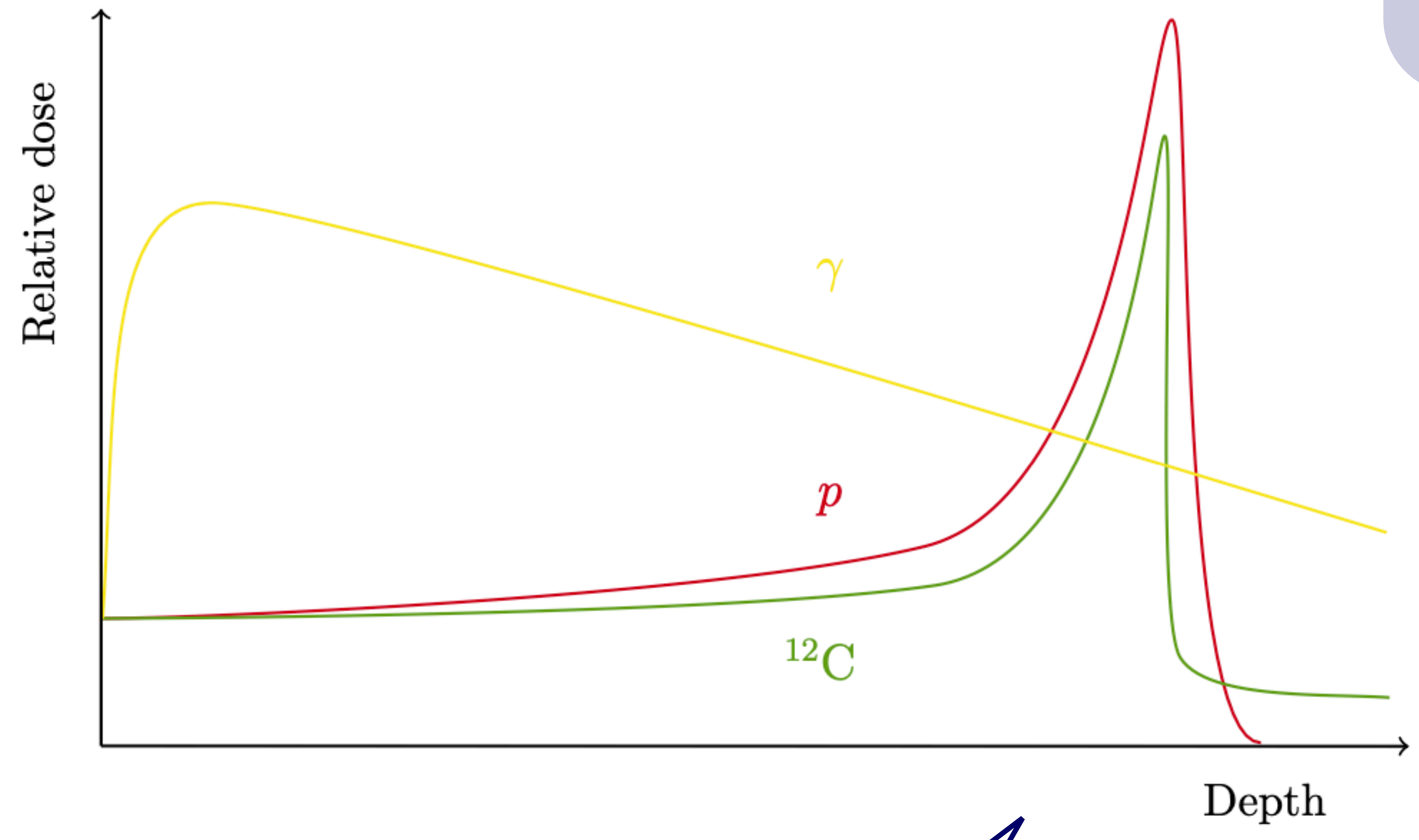

Hadrontherapy

Space radio-protection

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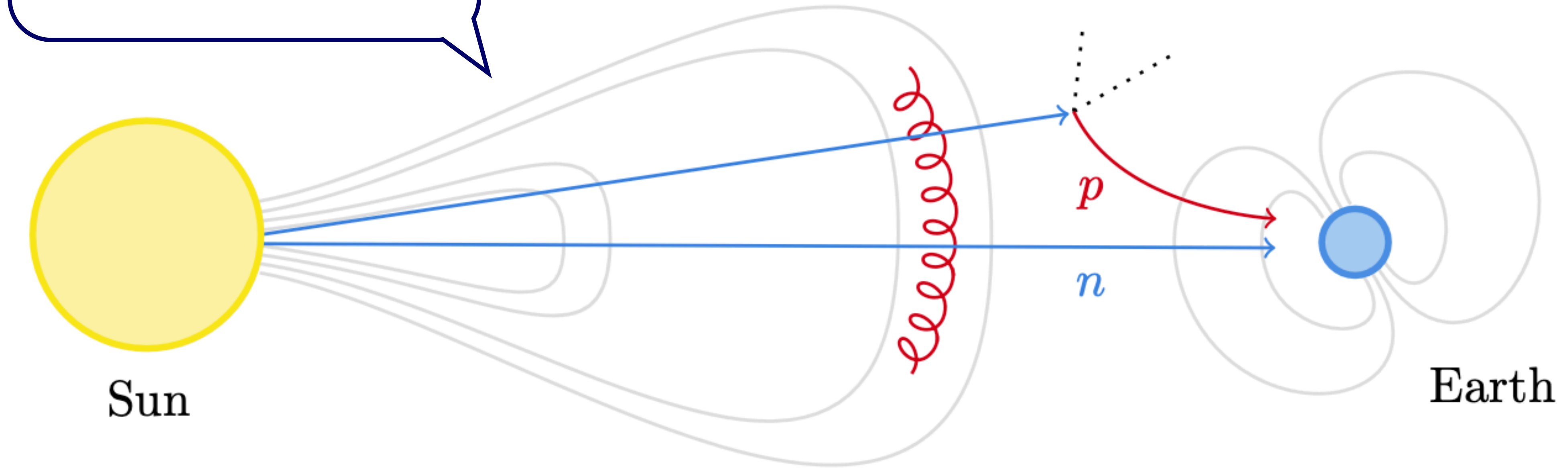

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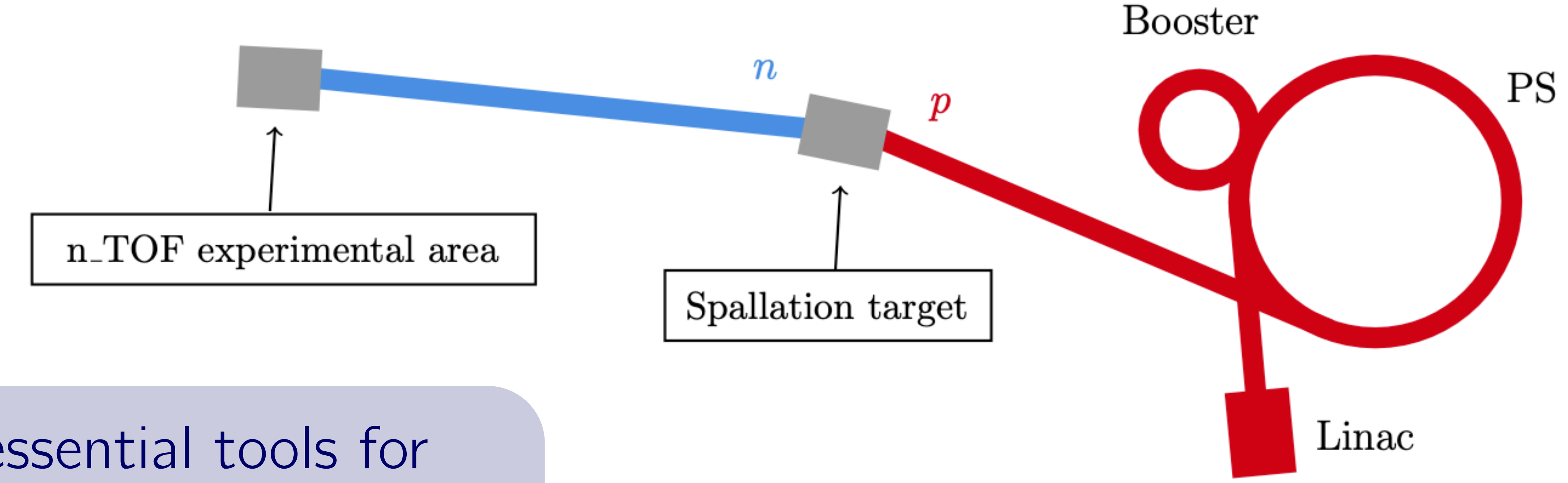

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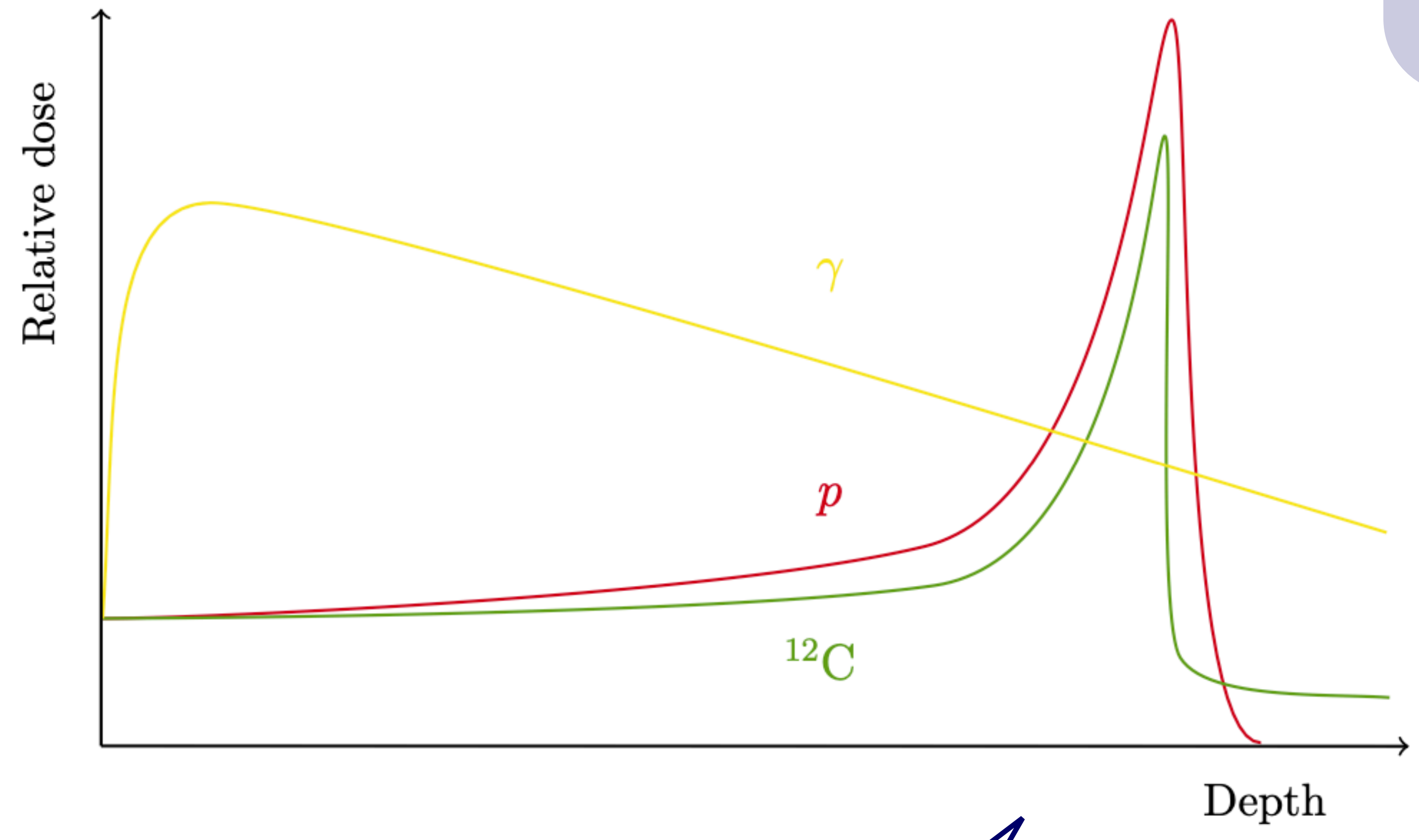

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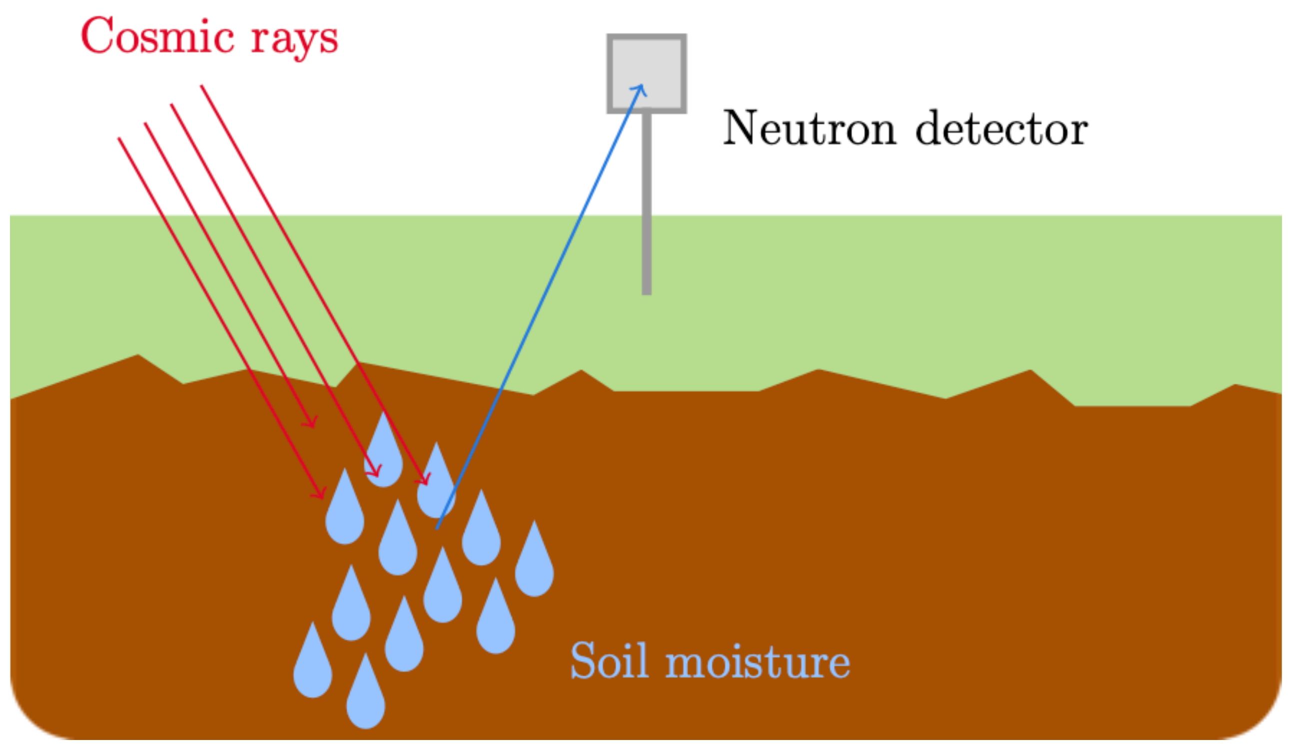
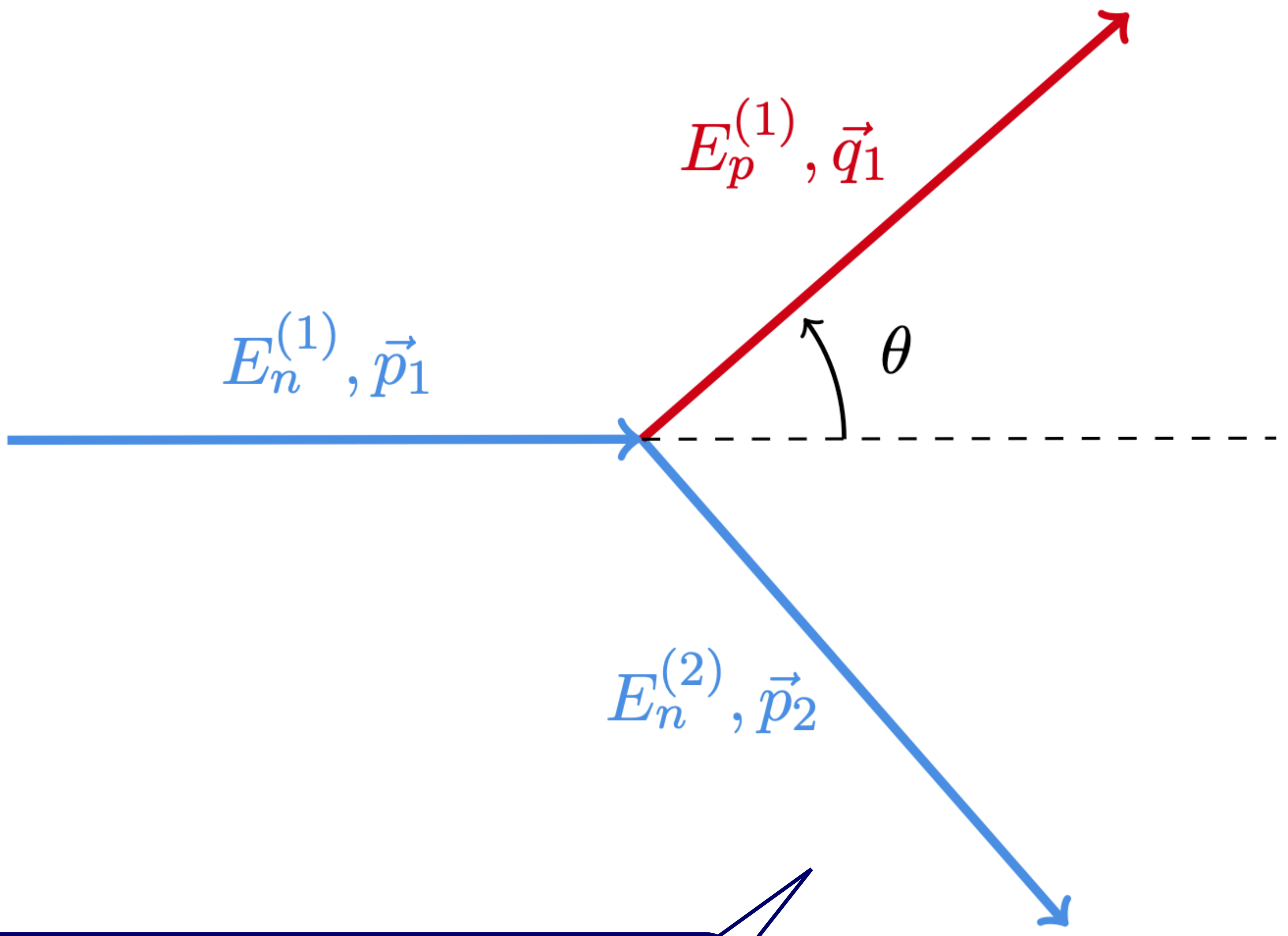


Environmental physics

Techniques for Recoil Proton Track Imaging

Fast neutrons and protons interact mainly via elastic scattering

$$E_n = \frac{E_p}{\cos^2 \theta}$$



If the neutron source is known a single scattering is sufficient

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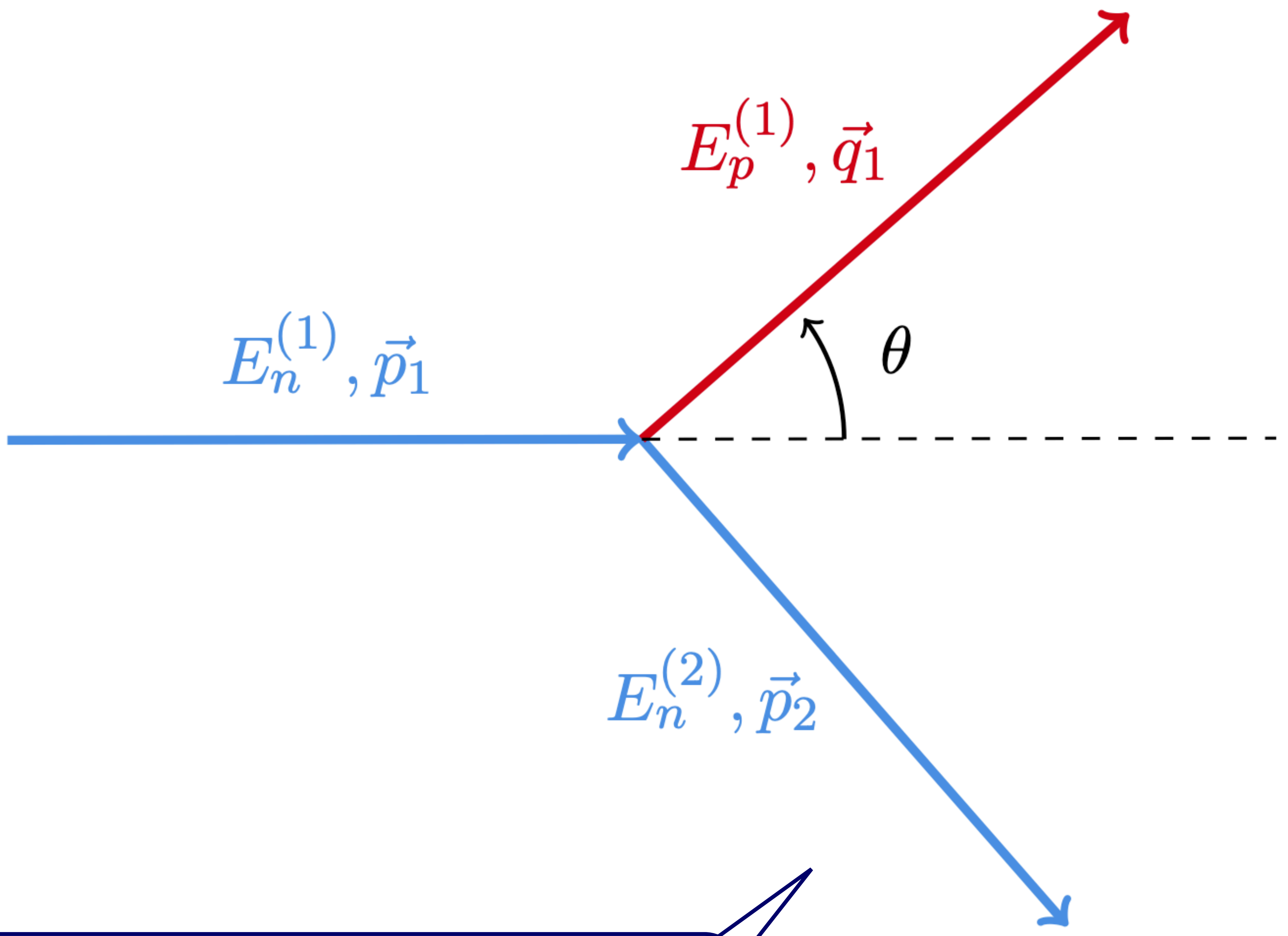

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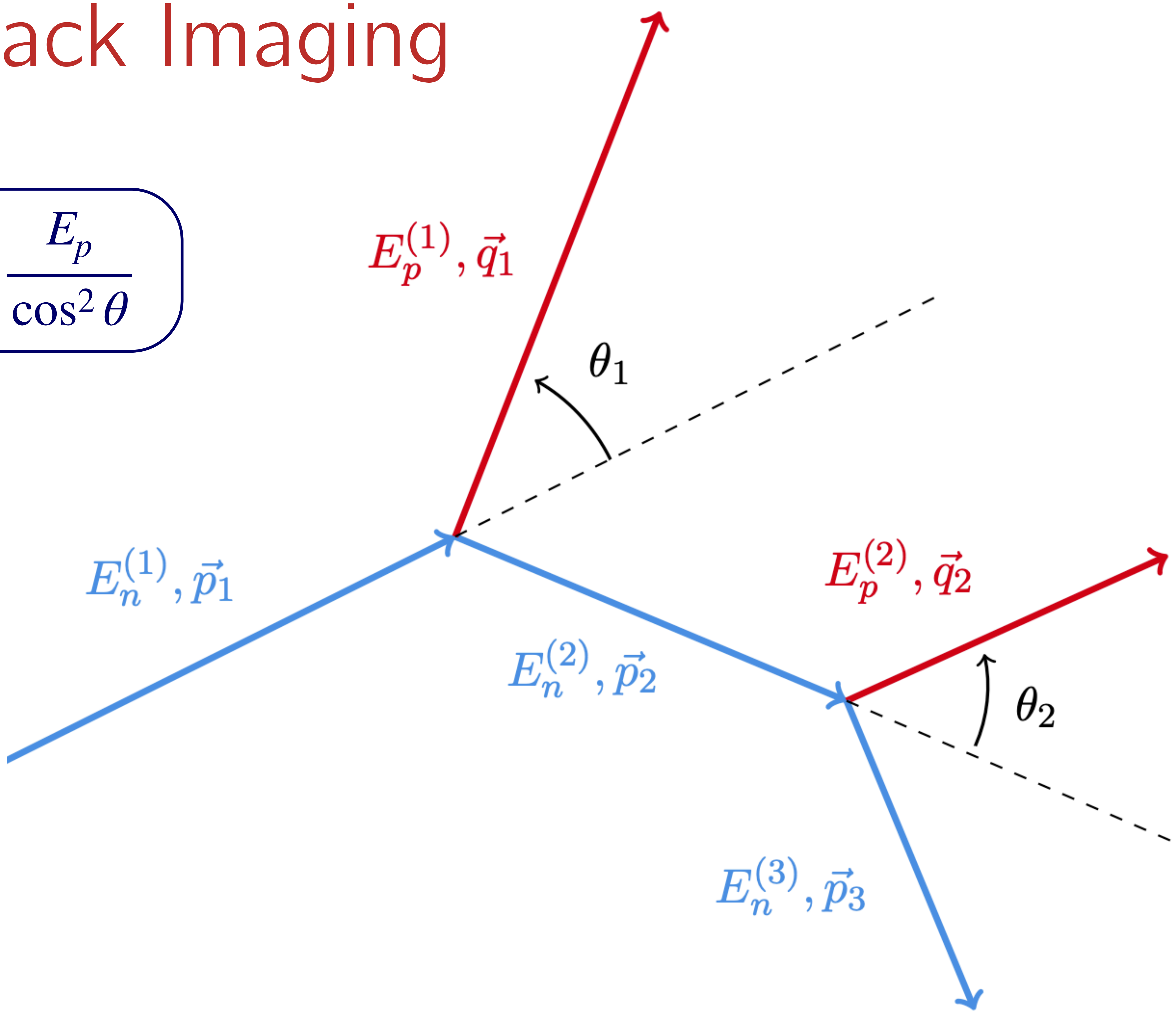
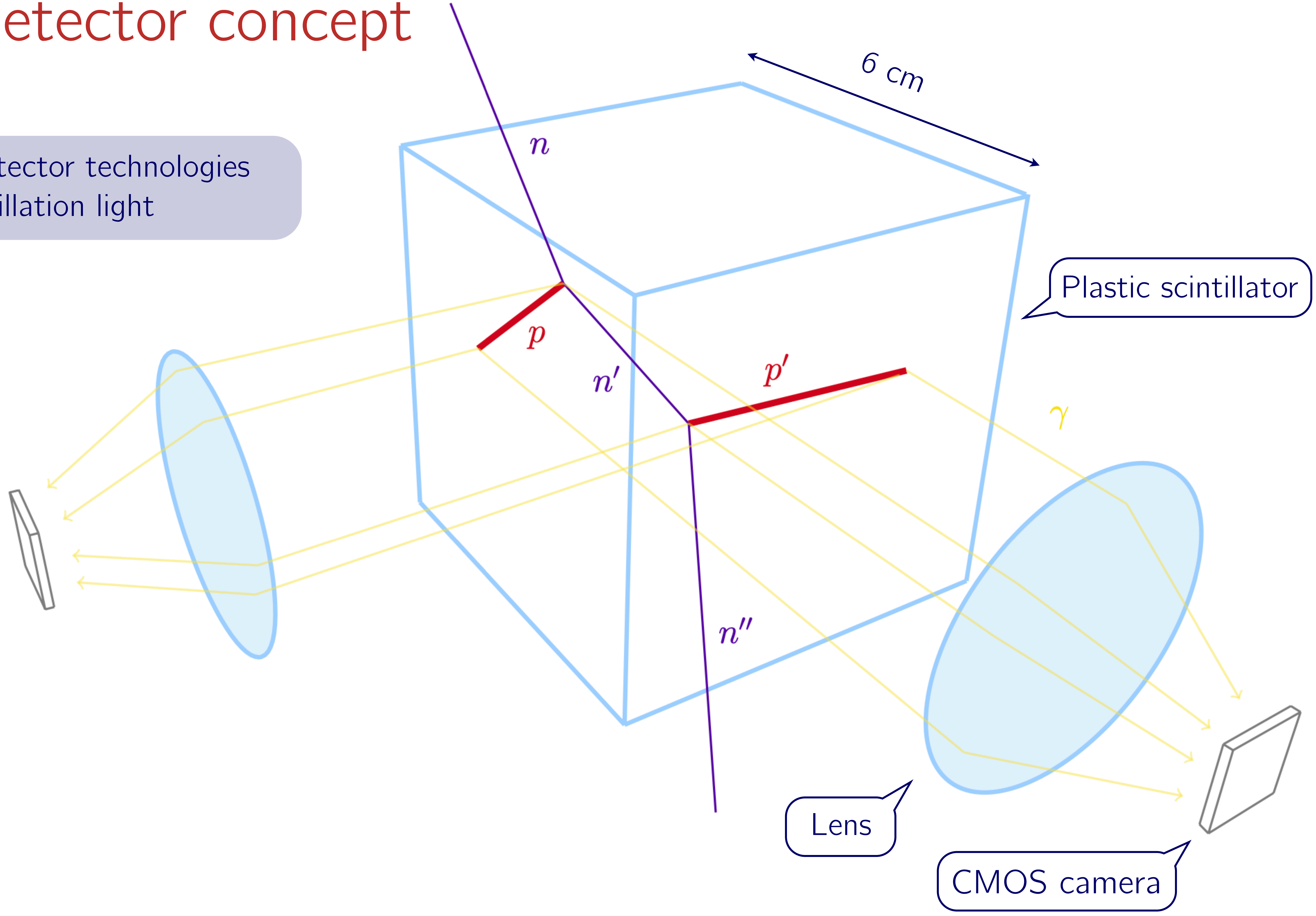


If the neutron source is NOT known a double scattering is needed

The RIPTIDE detector concept

Advancements in silicon detector technologies enable the imaging of scintillation light



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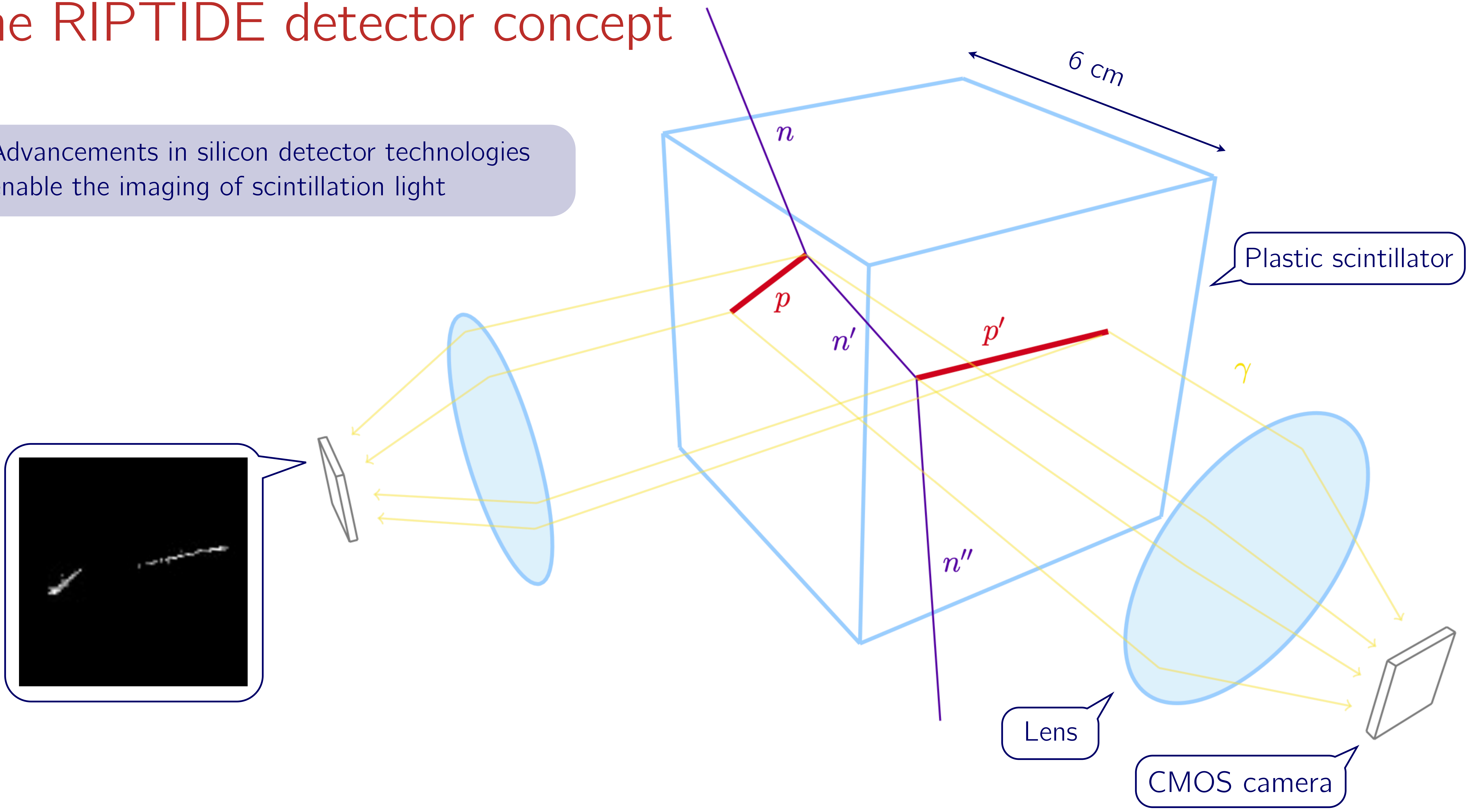
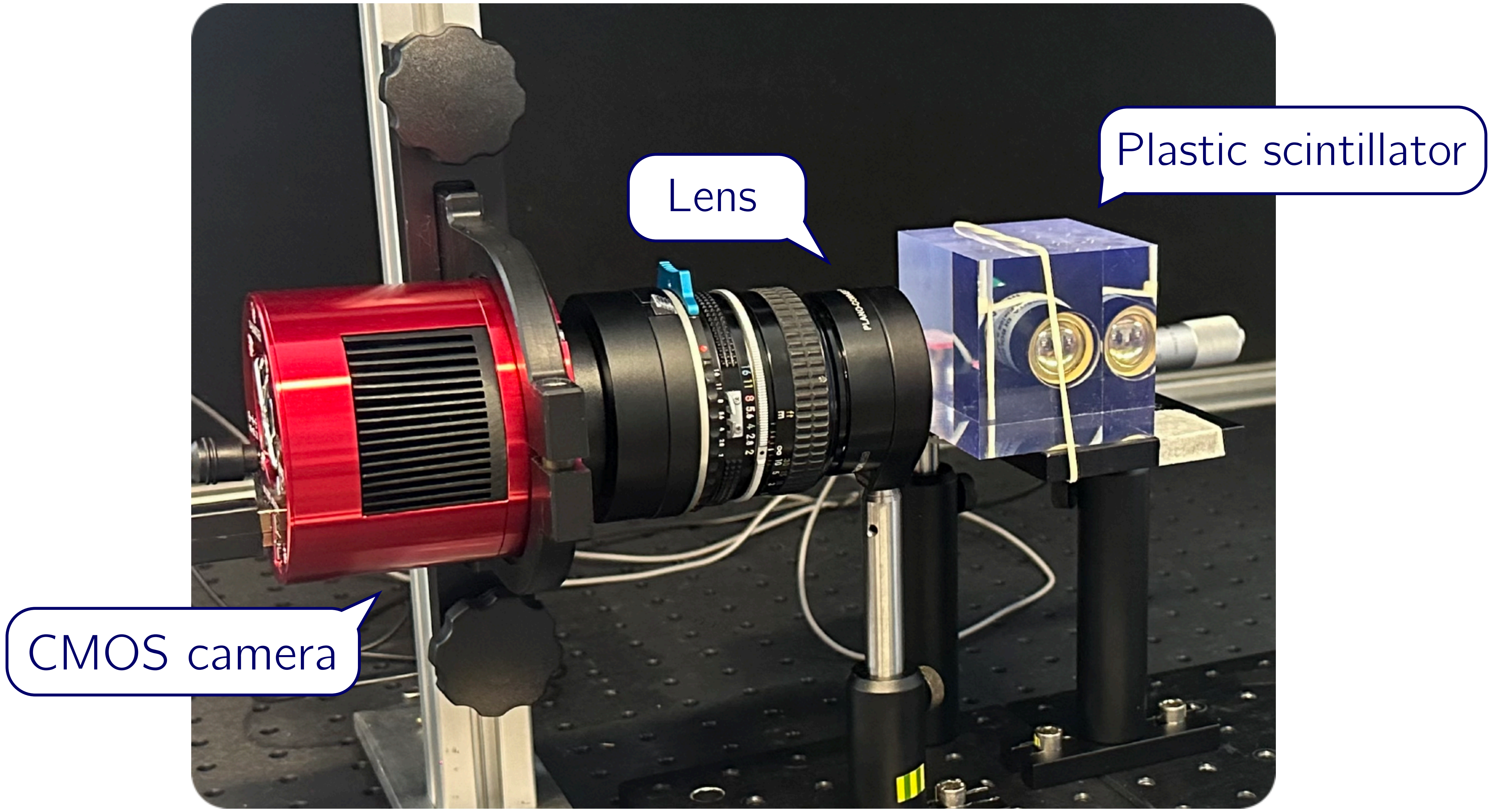
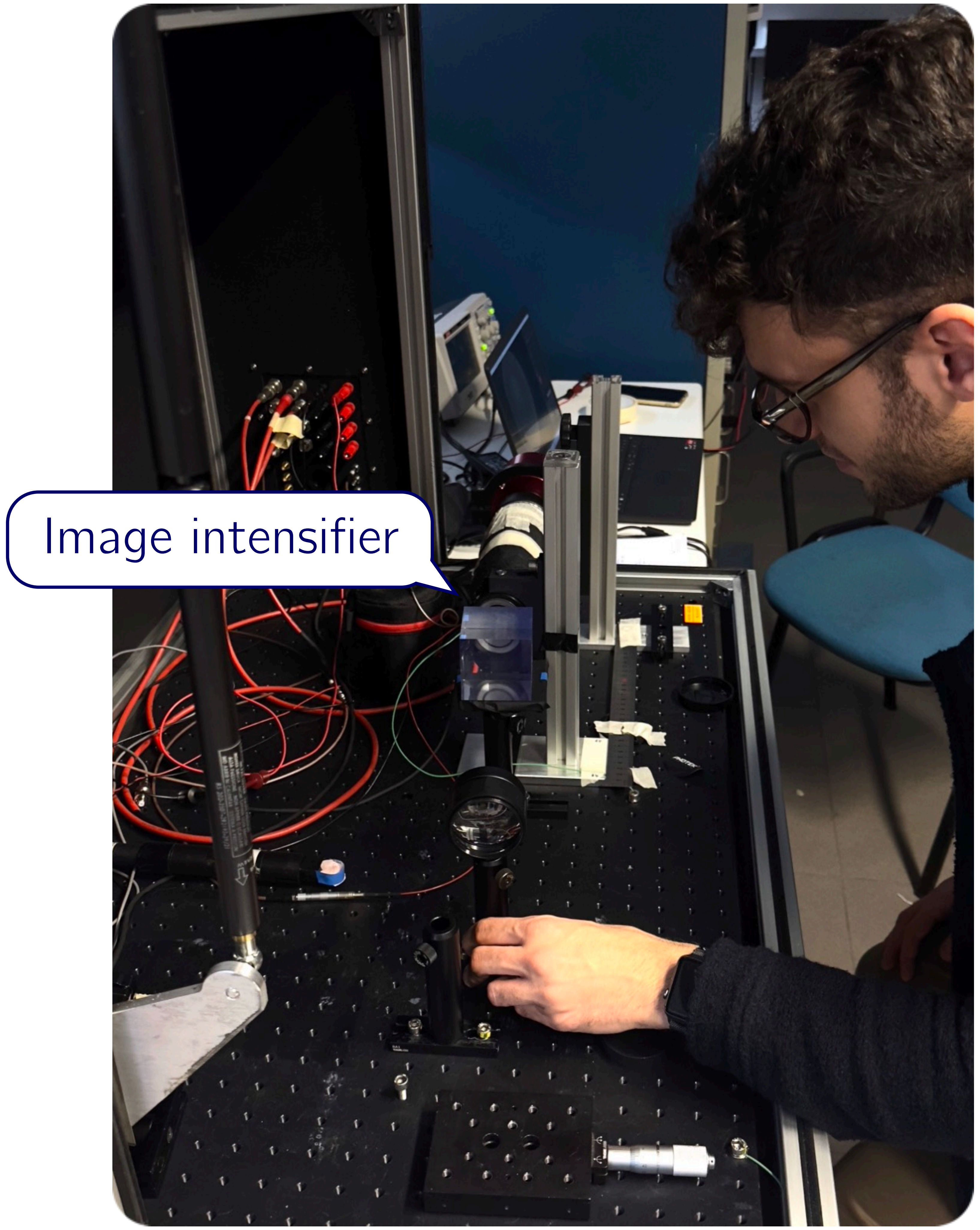


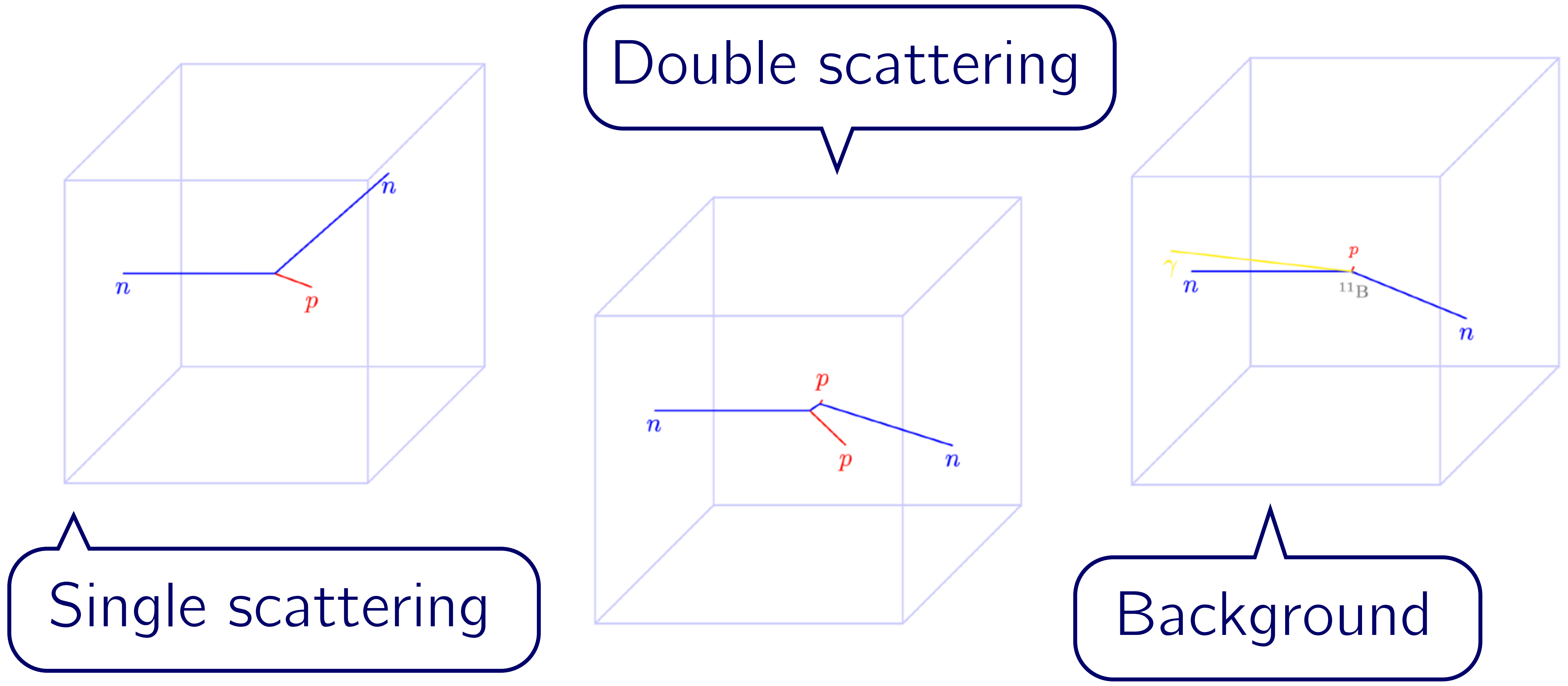
RIPTIDE: current status





Parametric Monte Carlo simulations

A Geant4 simulation of 1M monoenergetic neutrons provides data on reactions within the scintillator



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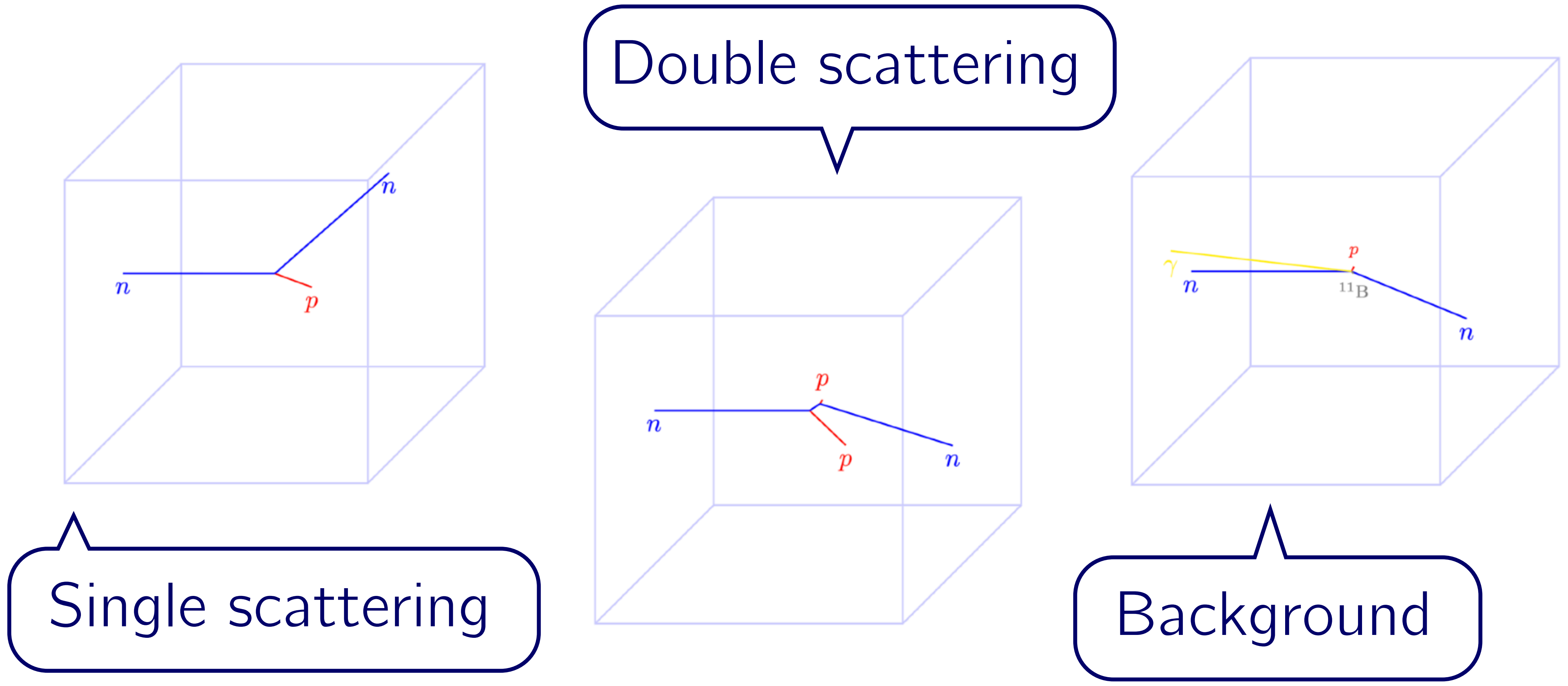

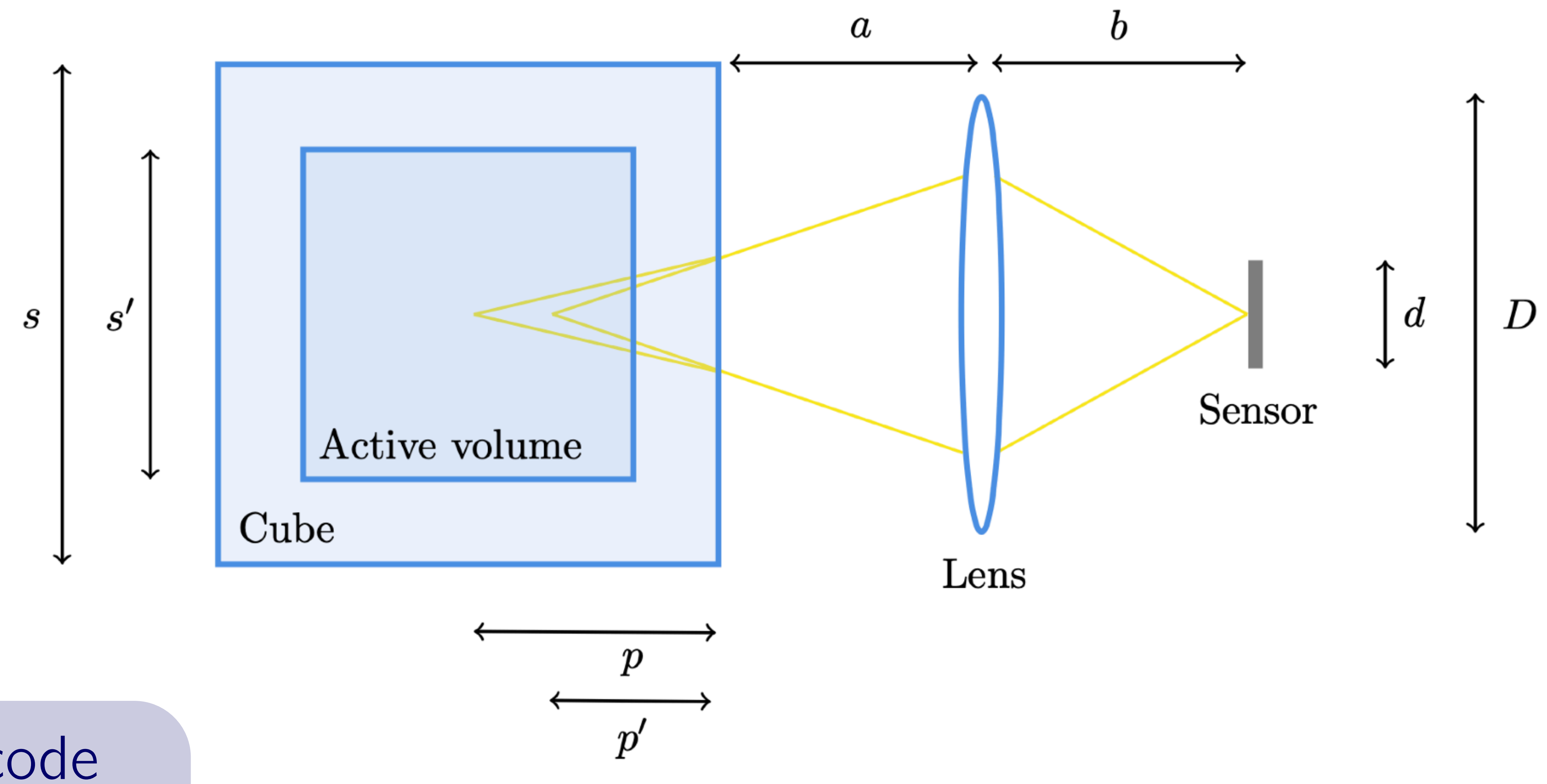

Scintillation optical photons are propagated using a custom code introducing optical aberrations, primarily spherical aberration

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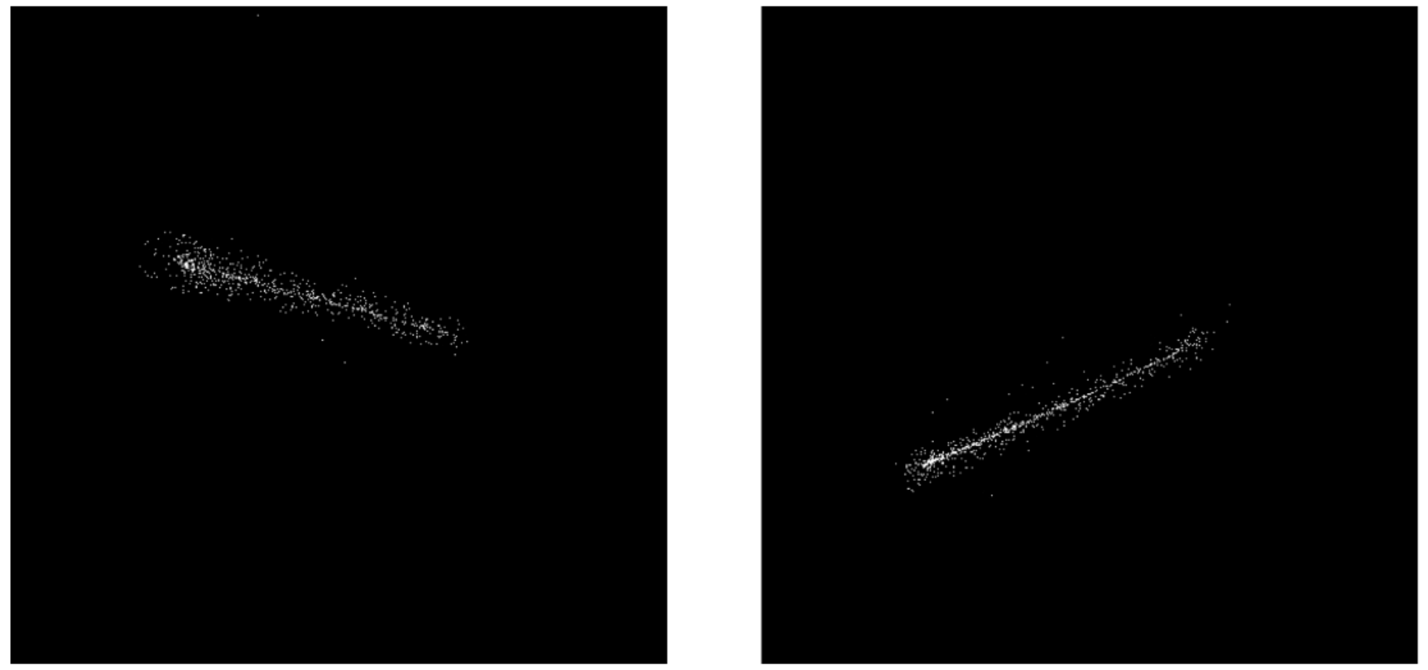
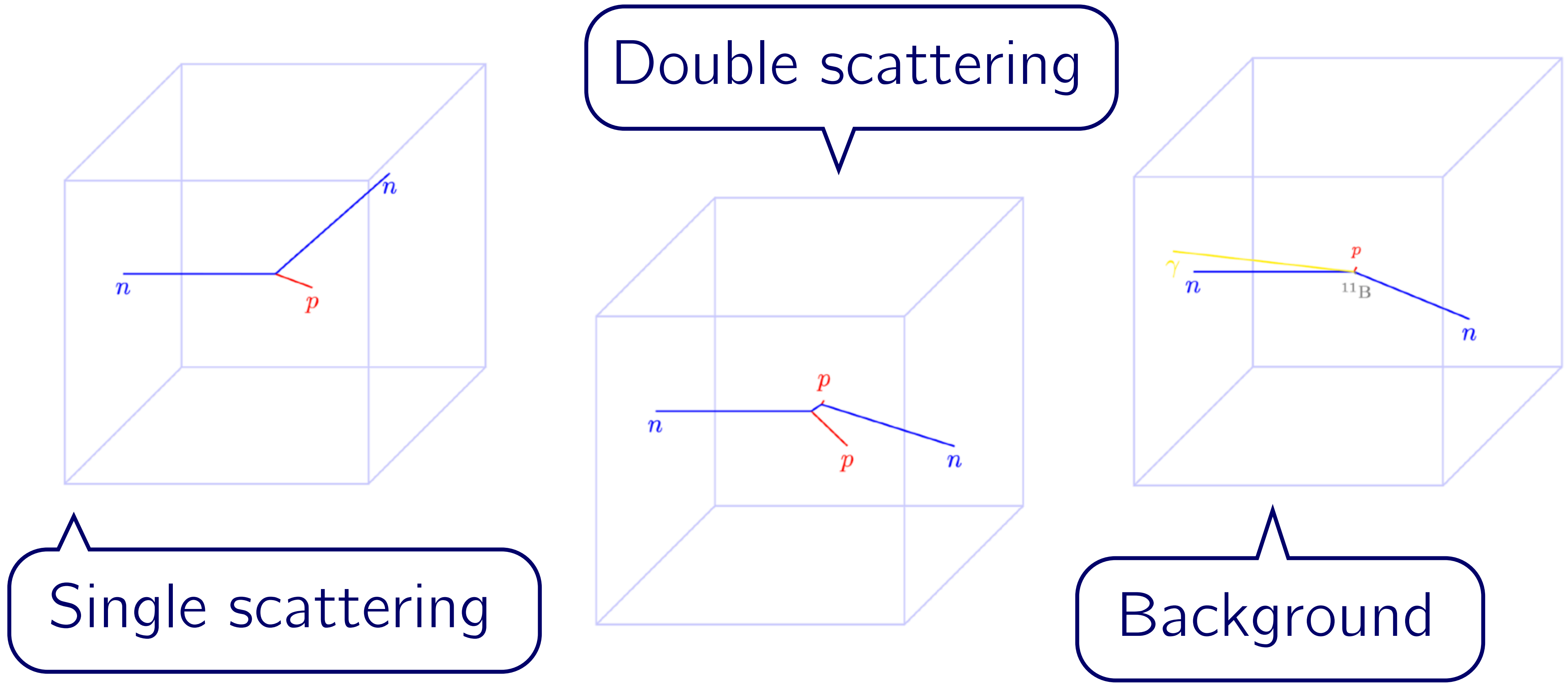
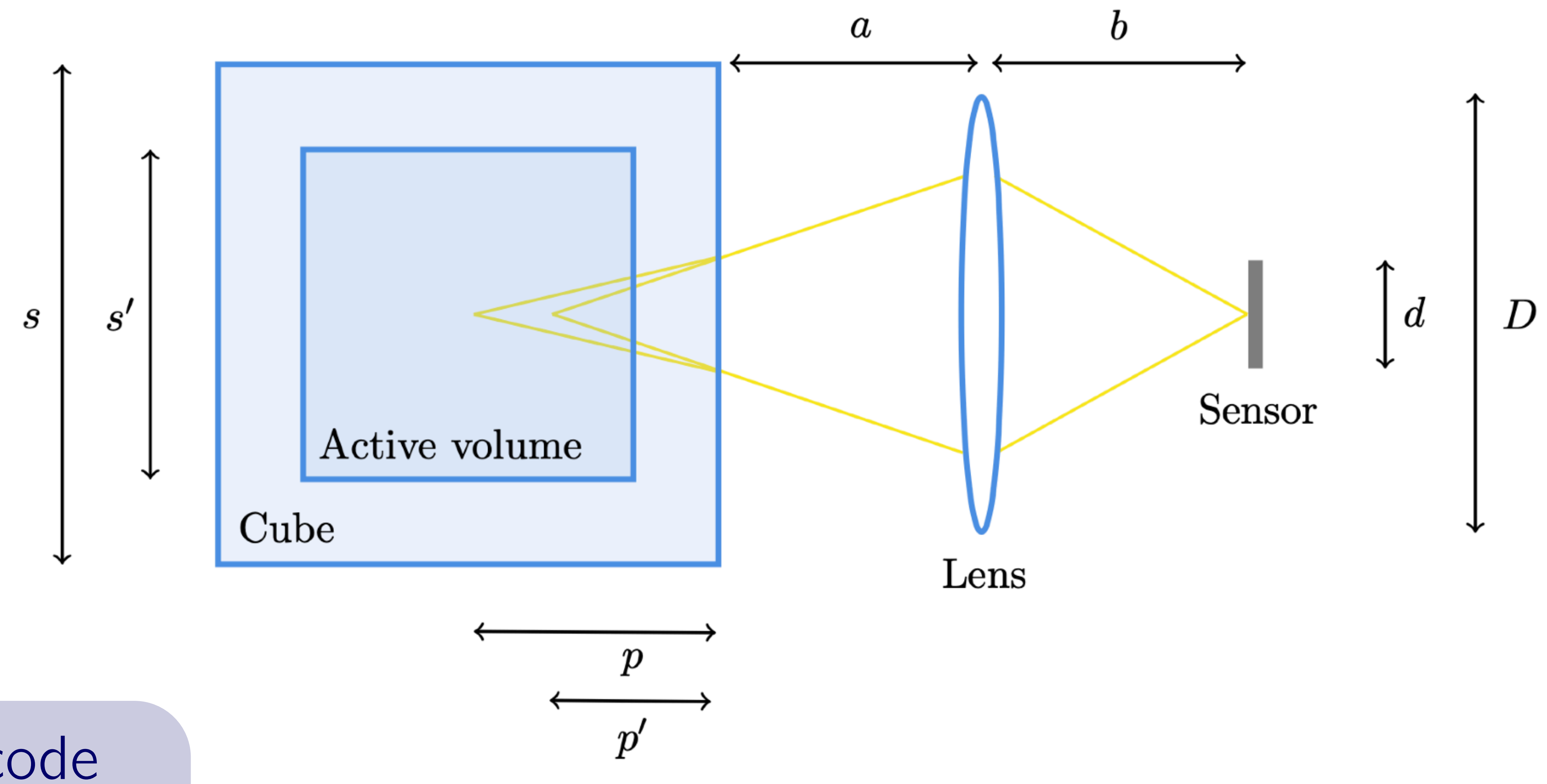
Two projections on the sensor are used for the analysis







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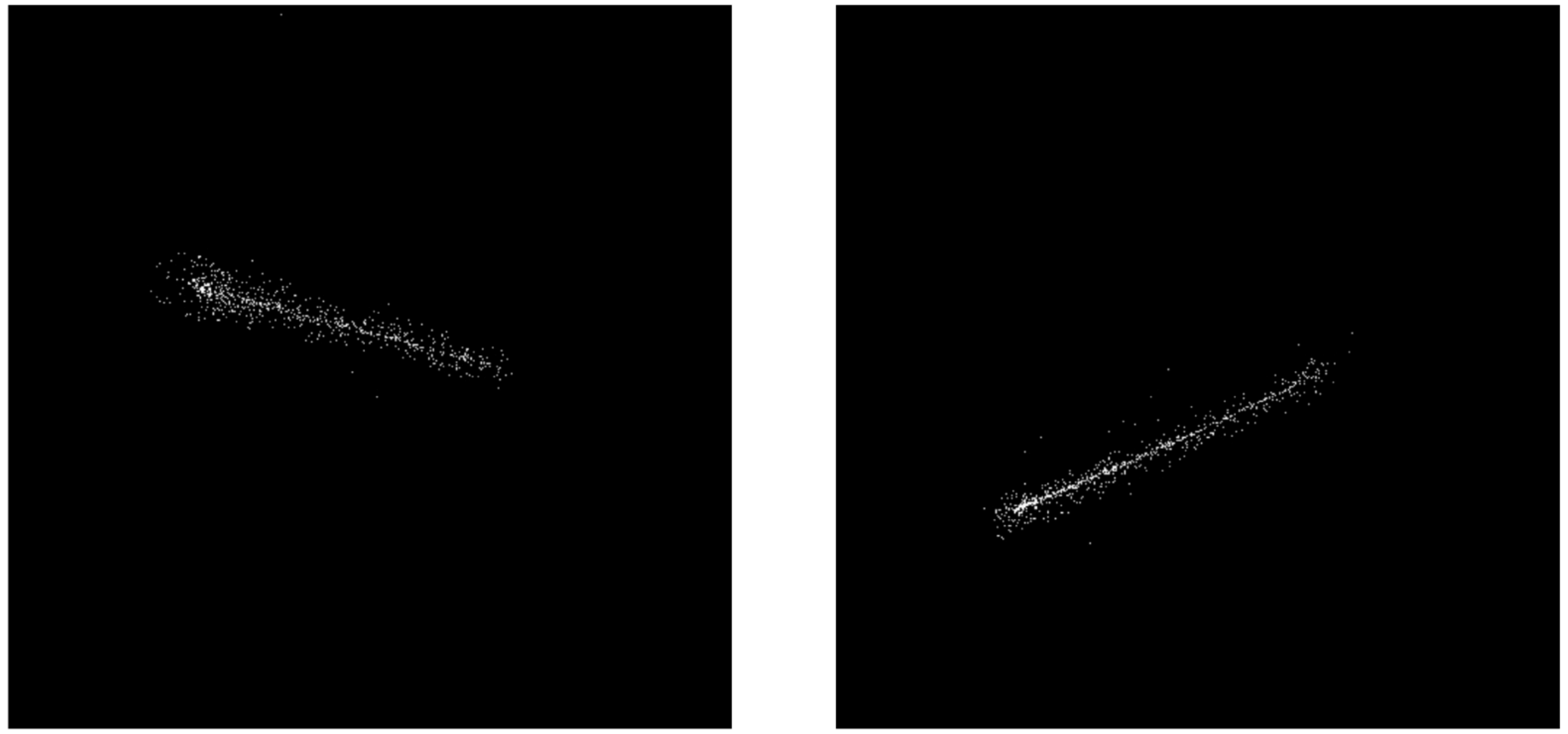
Proton reconstruction from its projections



+XZ +XY

1 Direction

2 Orientation

3 Energy

Proton track direction

Find the 2D direction of the projected tracks with the **Hough transform**

Each (u, v) is mapped using $\rho = u \cos \theta + v \sin \theta$

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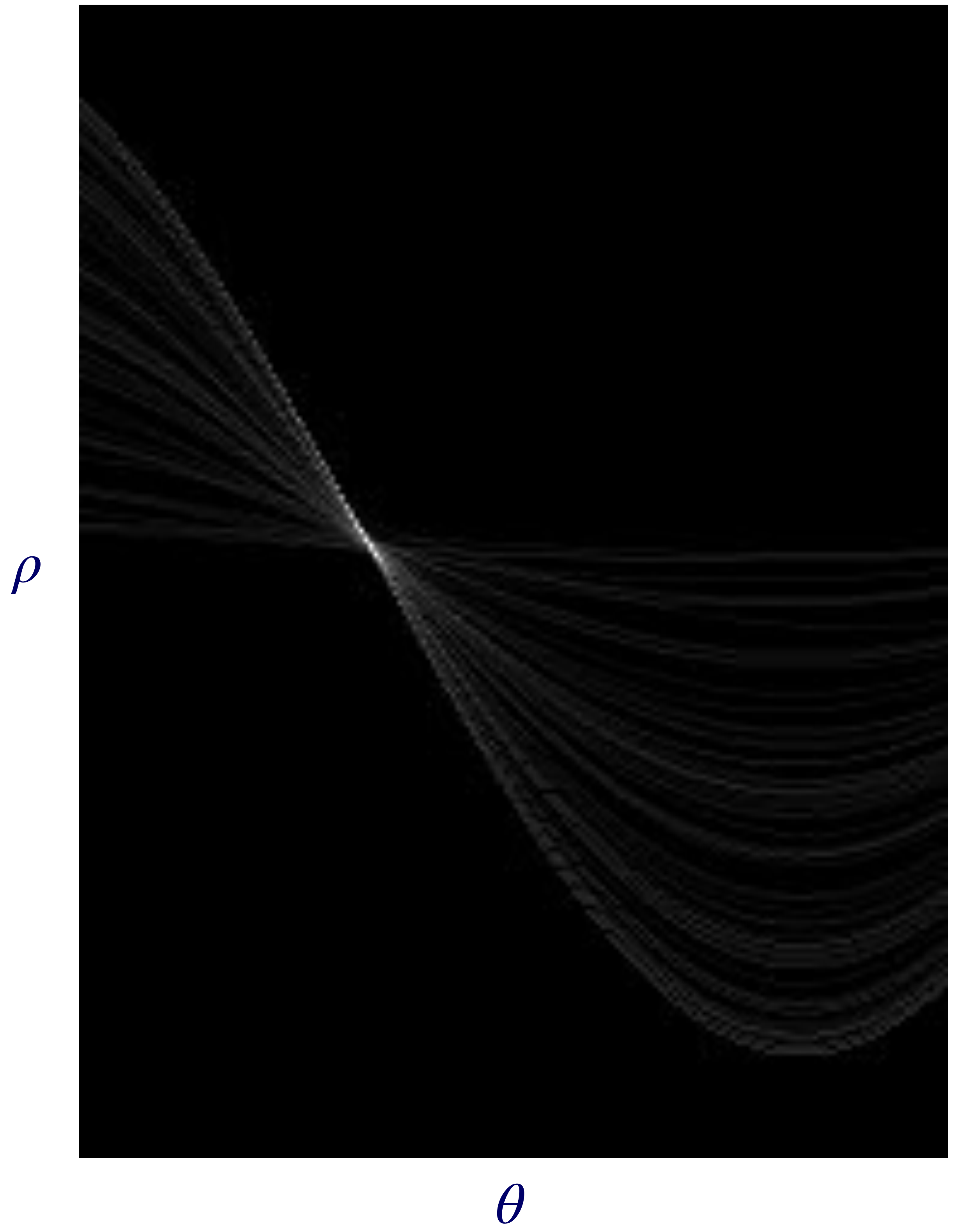

Fill the (ρ, θ) space and find the peak

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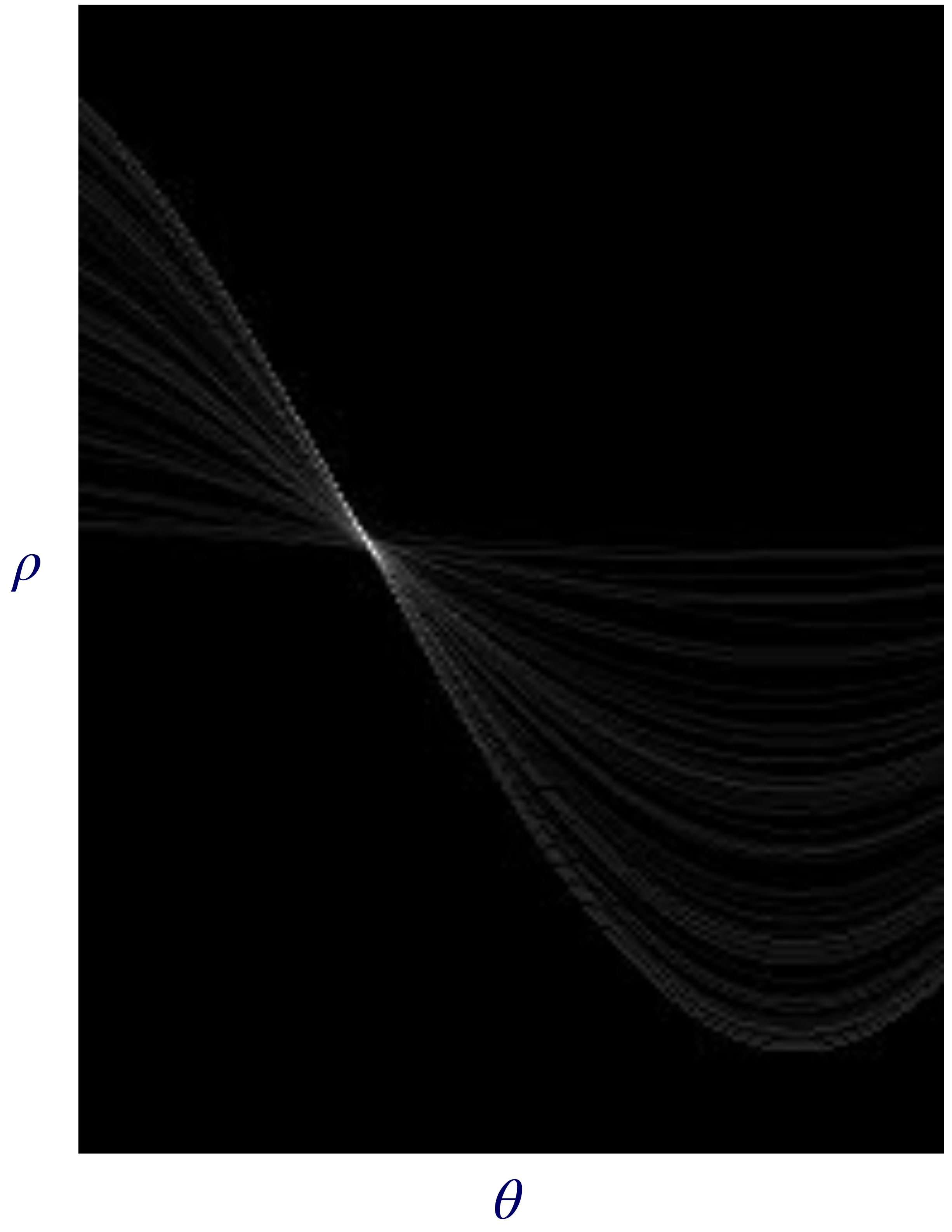

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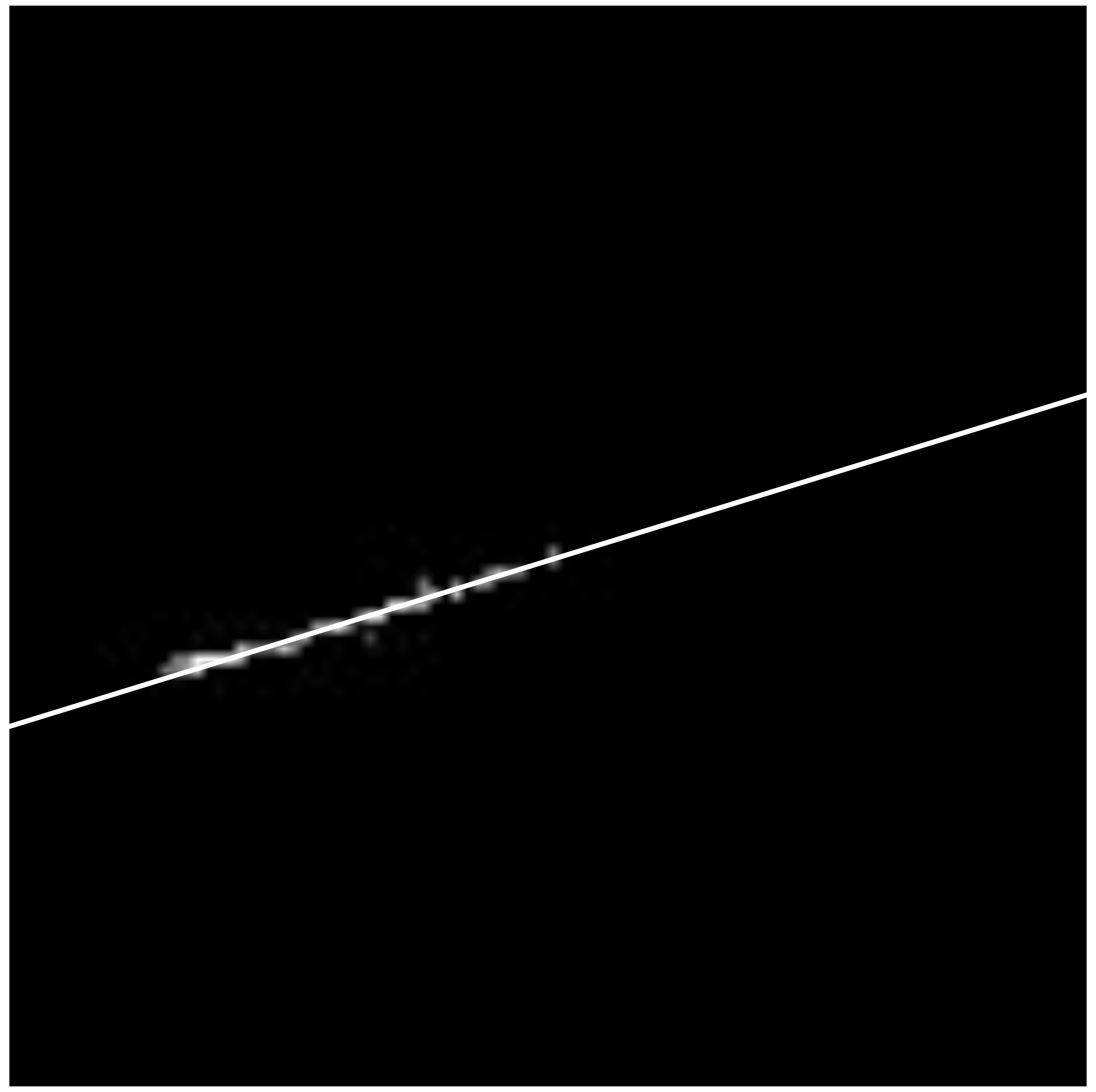


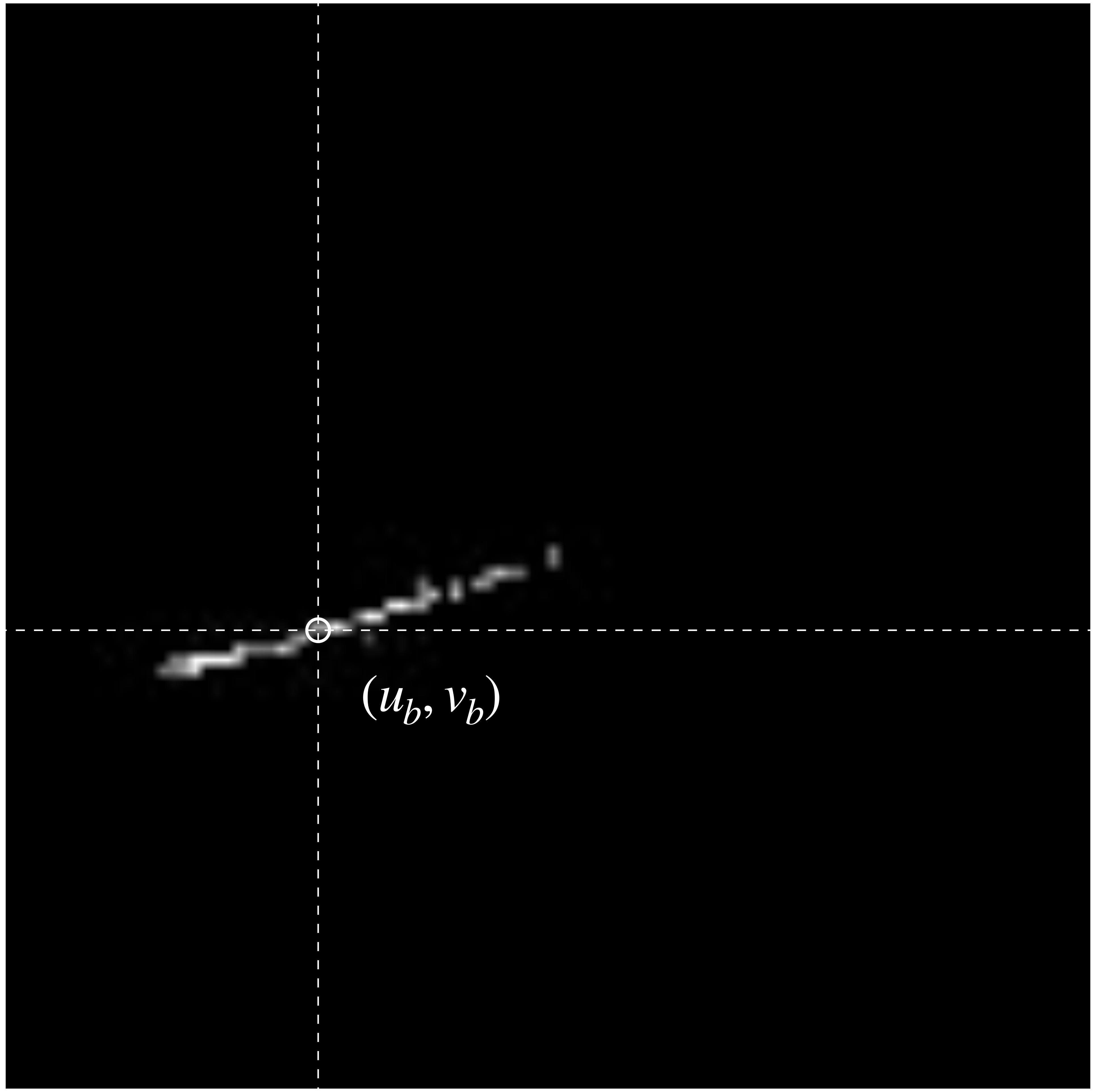
How to resolve the ambiguity in the orientation?

Proton track orientation

Barycentre

$$(u_b, v_b) = \left(\frac{\sum_i w_i u_i}{\sum_i w_i}, \frac{\sum_i w_i v_i}{\sum_i w_i} \right)$$

$$u_i \rightarrow u_i - u_b \qquad v_i \rightarrow v_i - v_b$$



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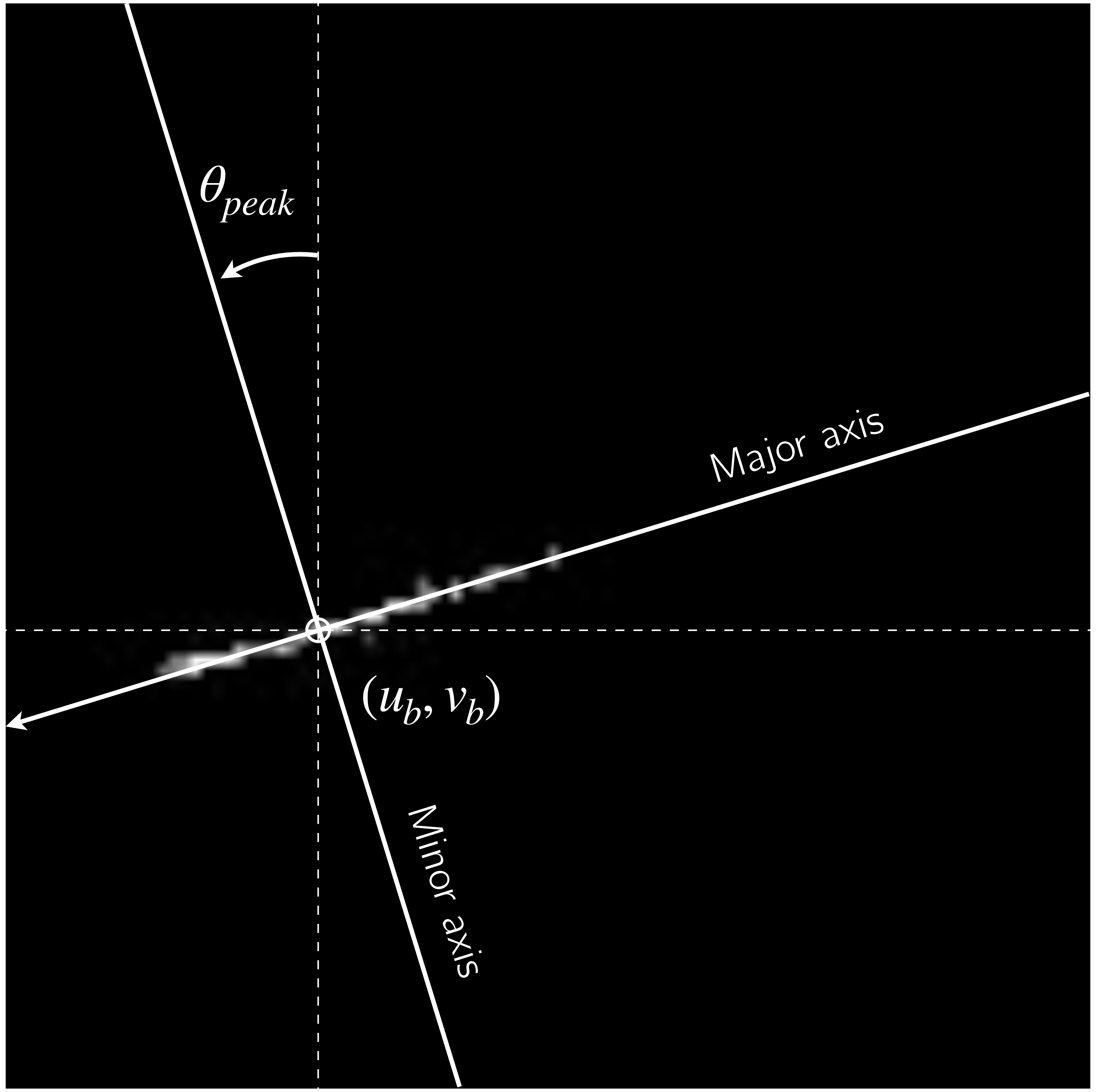
Rotation

$$\begin{pmatrix} u_i'(\theta) \\ v_i'(\theta) \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} u_i \\ v_i \end{pmatrix}$$



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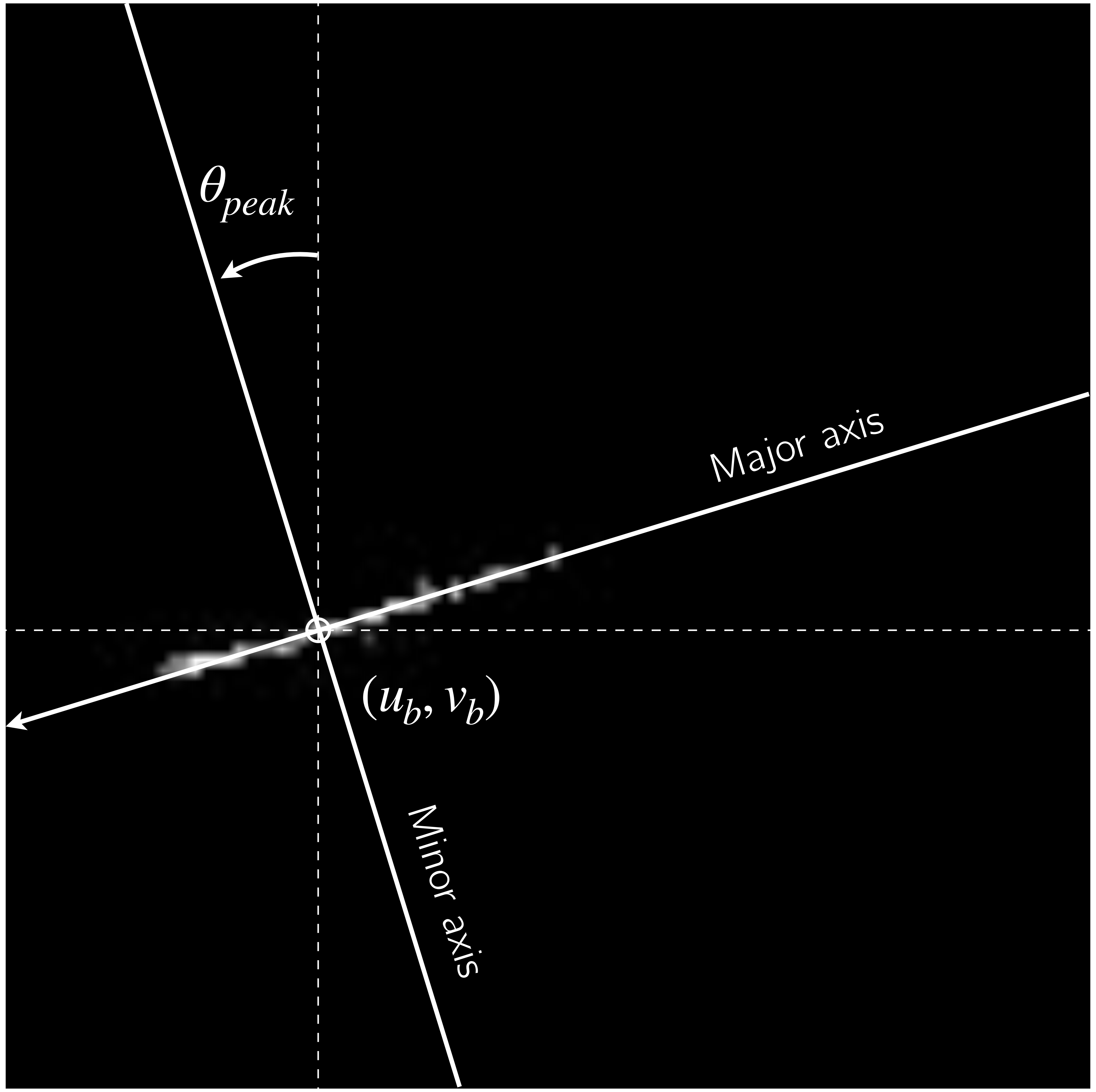
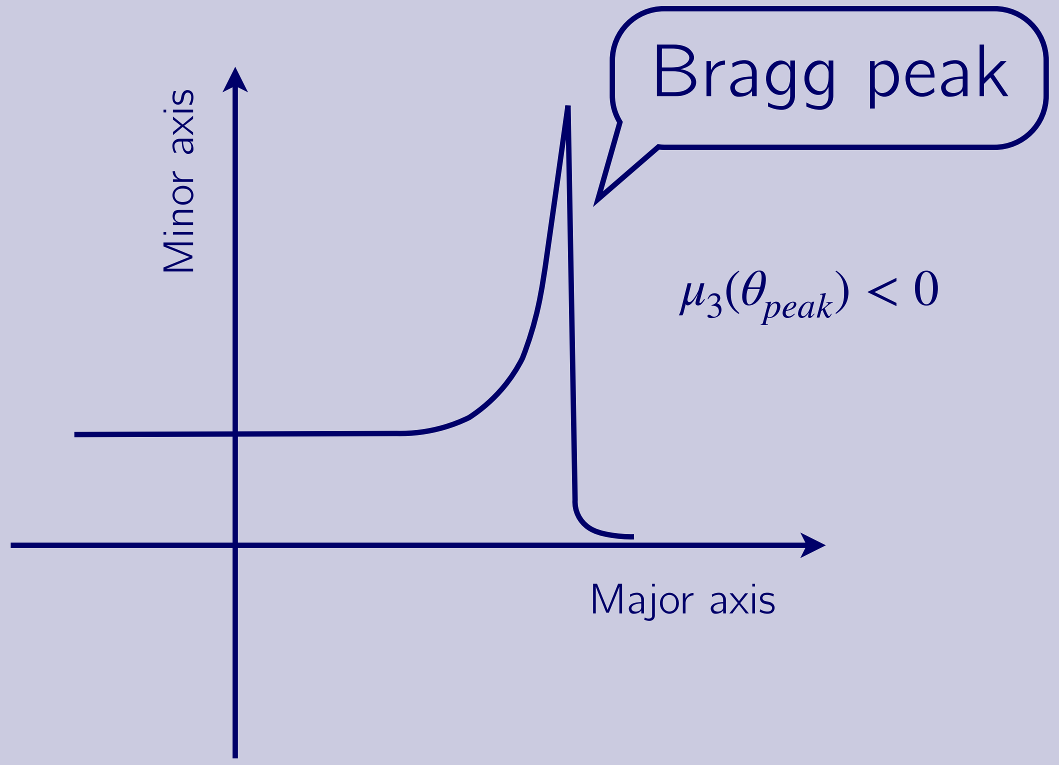


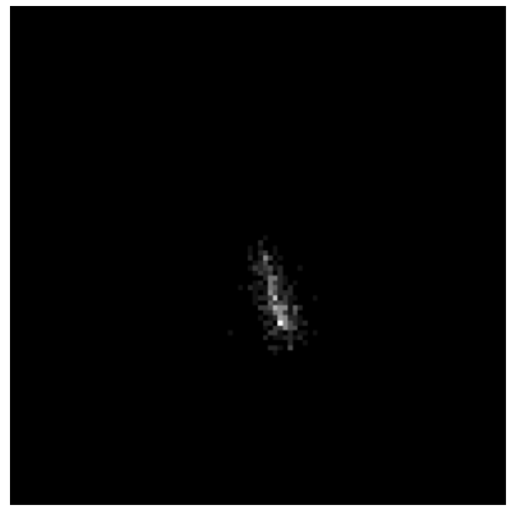
Skewness

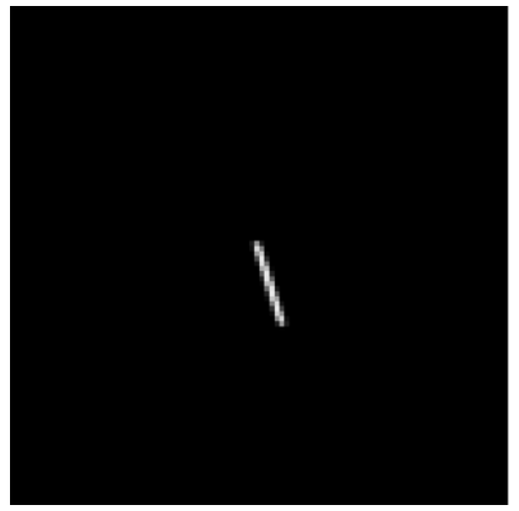
$$\mu_3 = \frac{\sum_i w_i (u_i \cos\theta_{peak} + v_i \sin\theta_{peak})^3}{\sum_i w_i}$$



Proton energy

Proton energy can be estimated from the 3D track length (Range) using $R = \alpha E^p$





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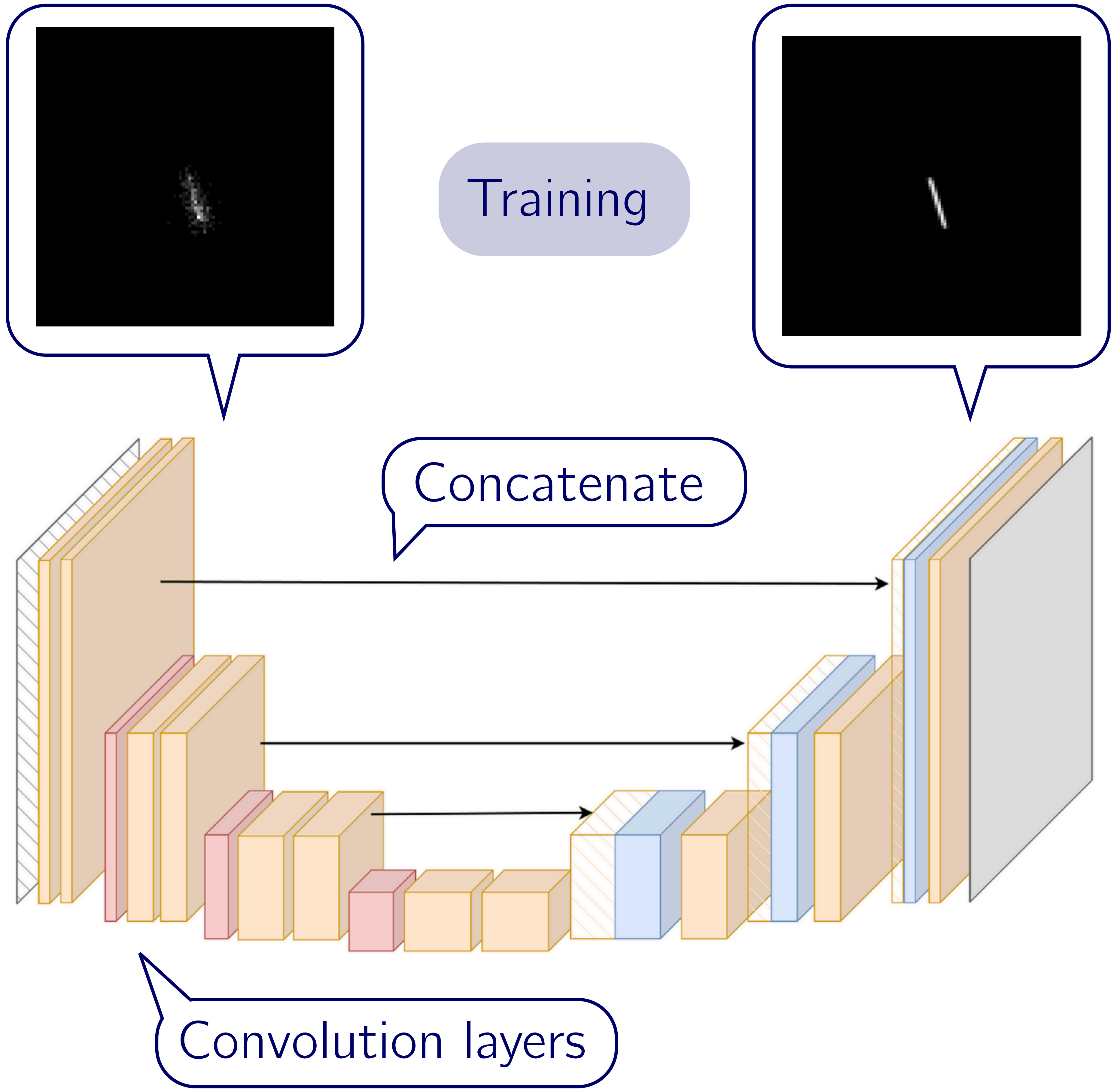

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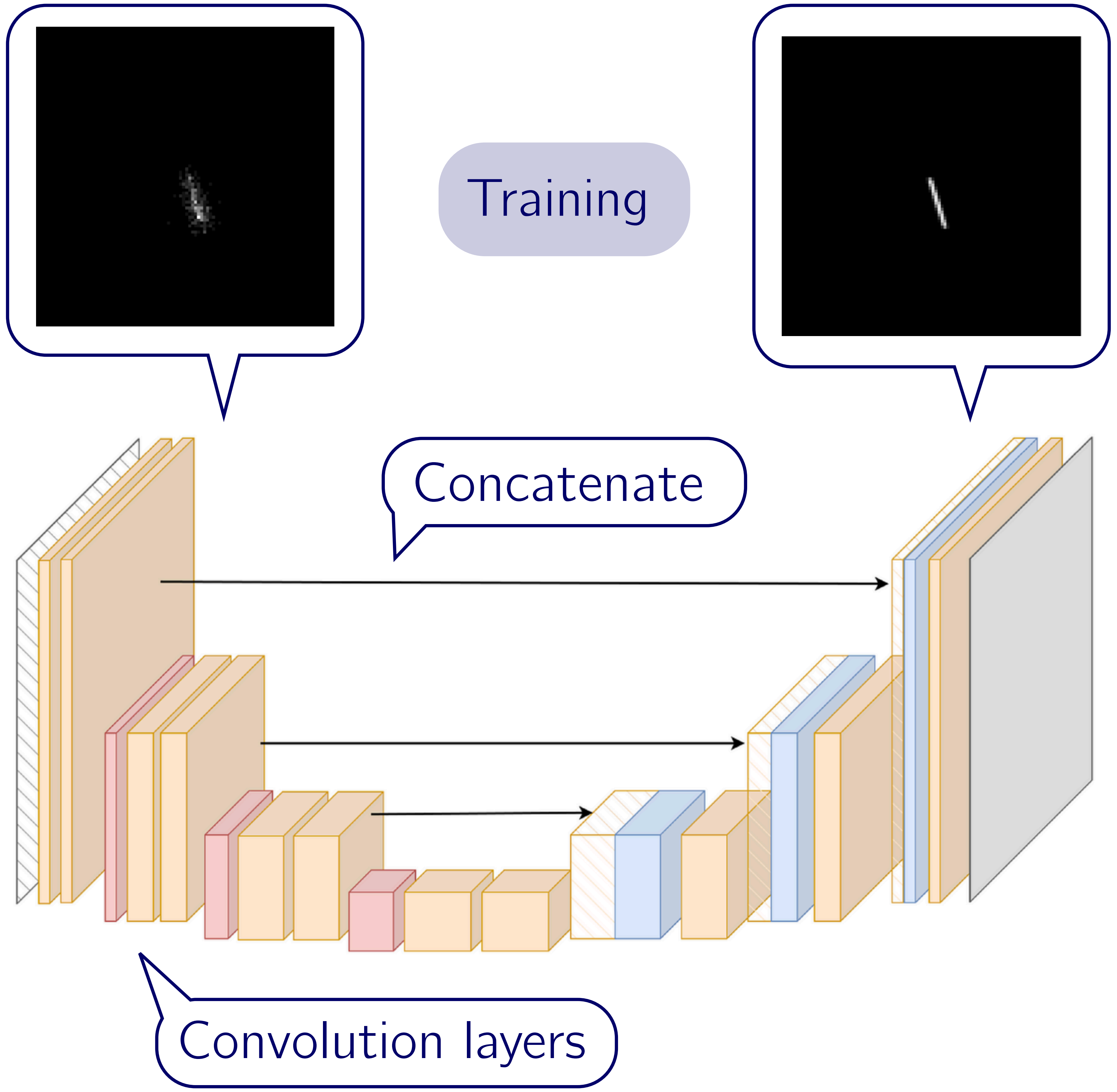
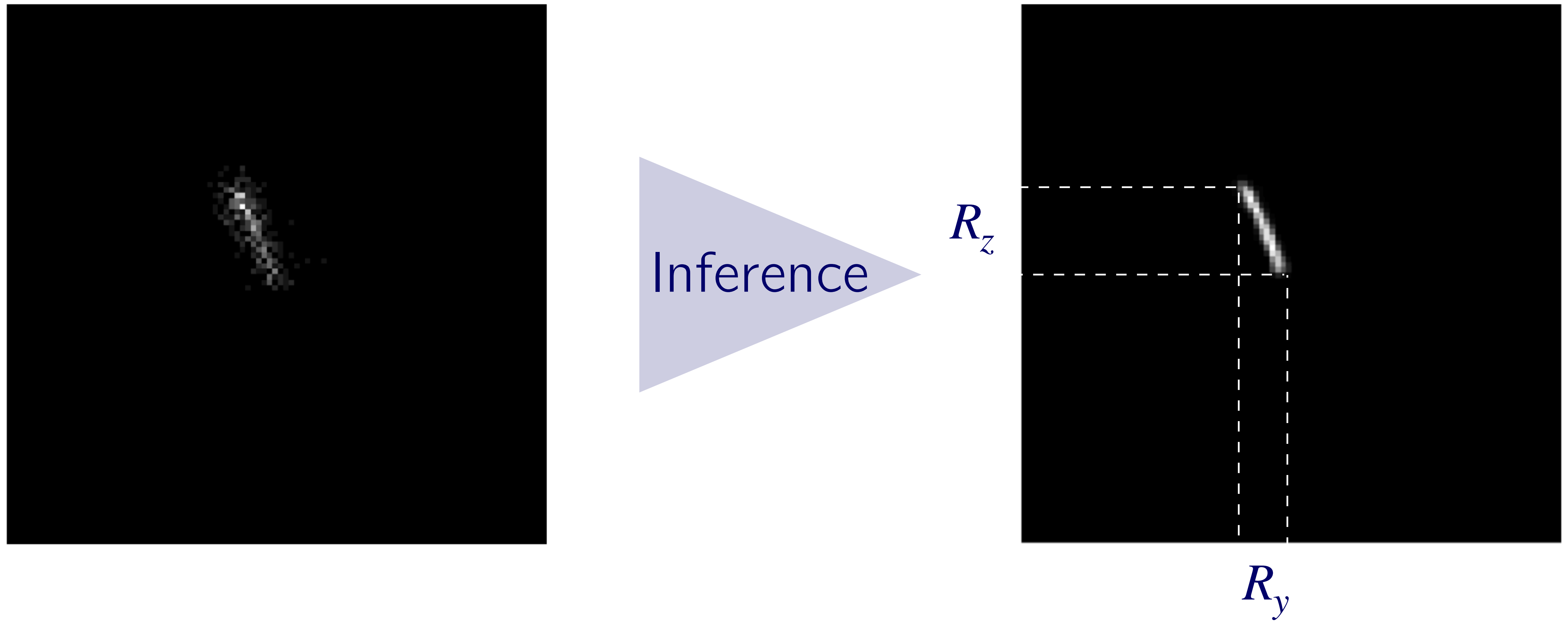
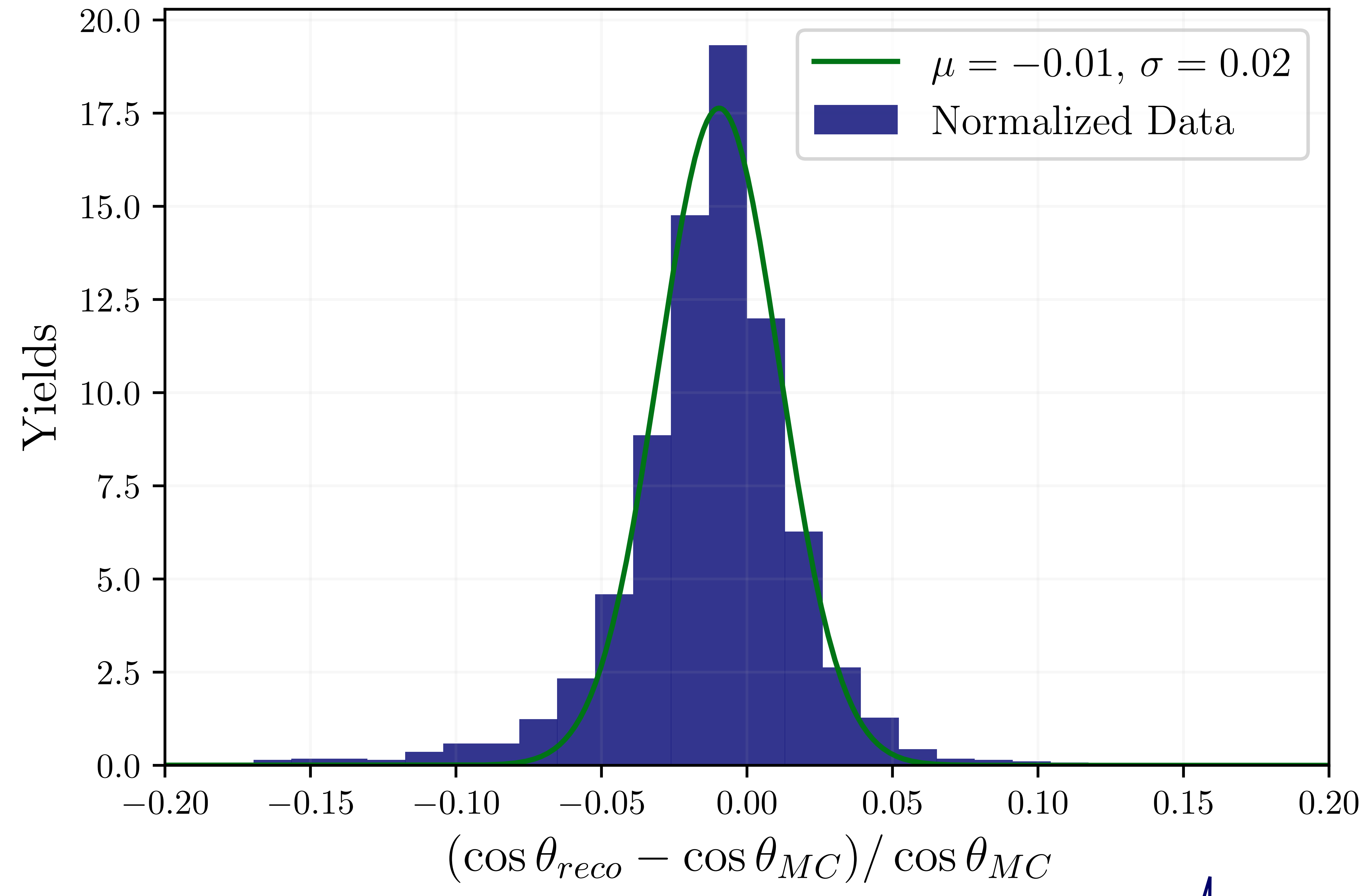
Range is calculated by projecting unaberrated tracks on each axis





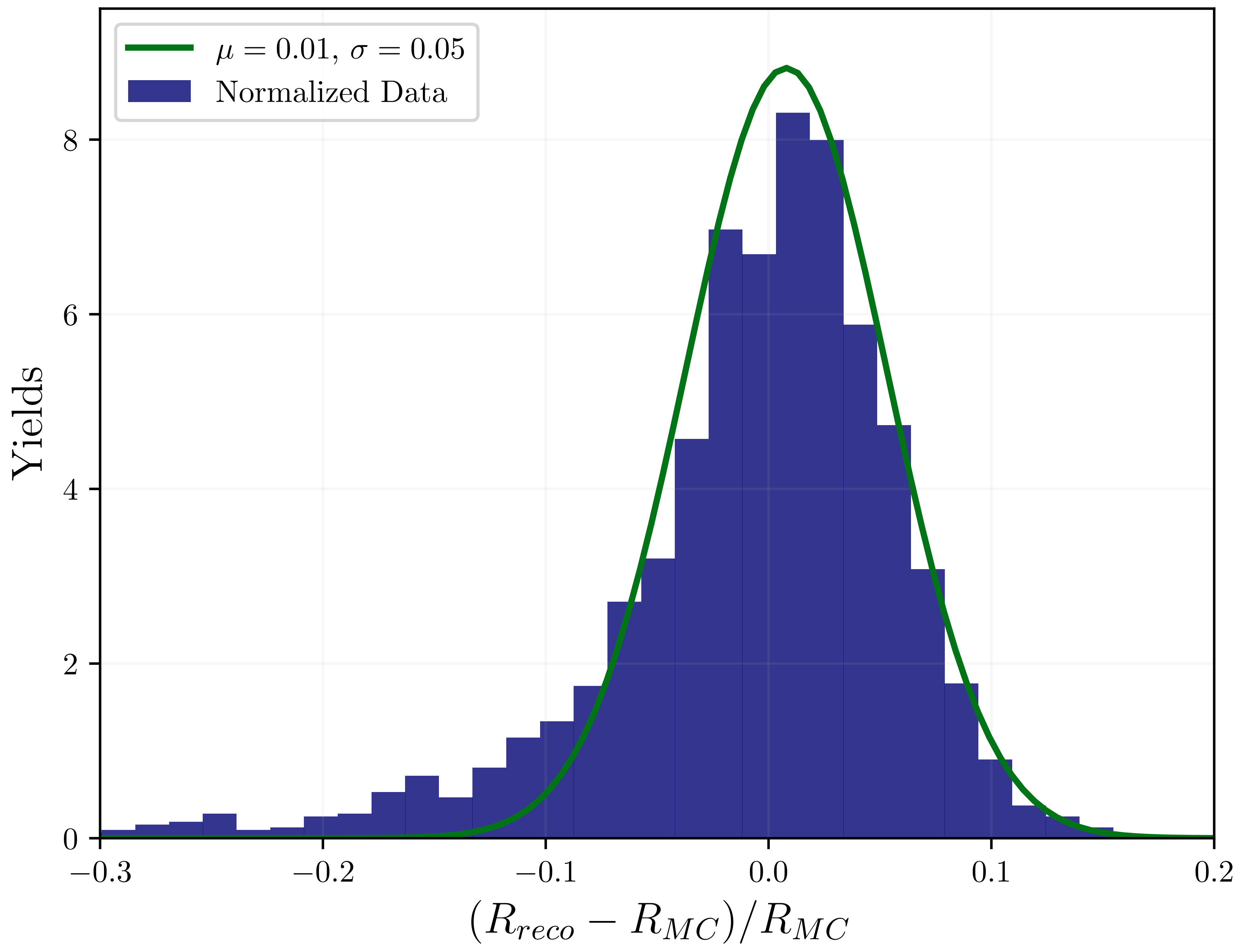
A UNet is used to remove aberrations in the range reconstruction

Results



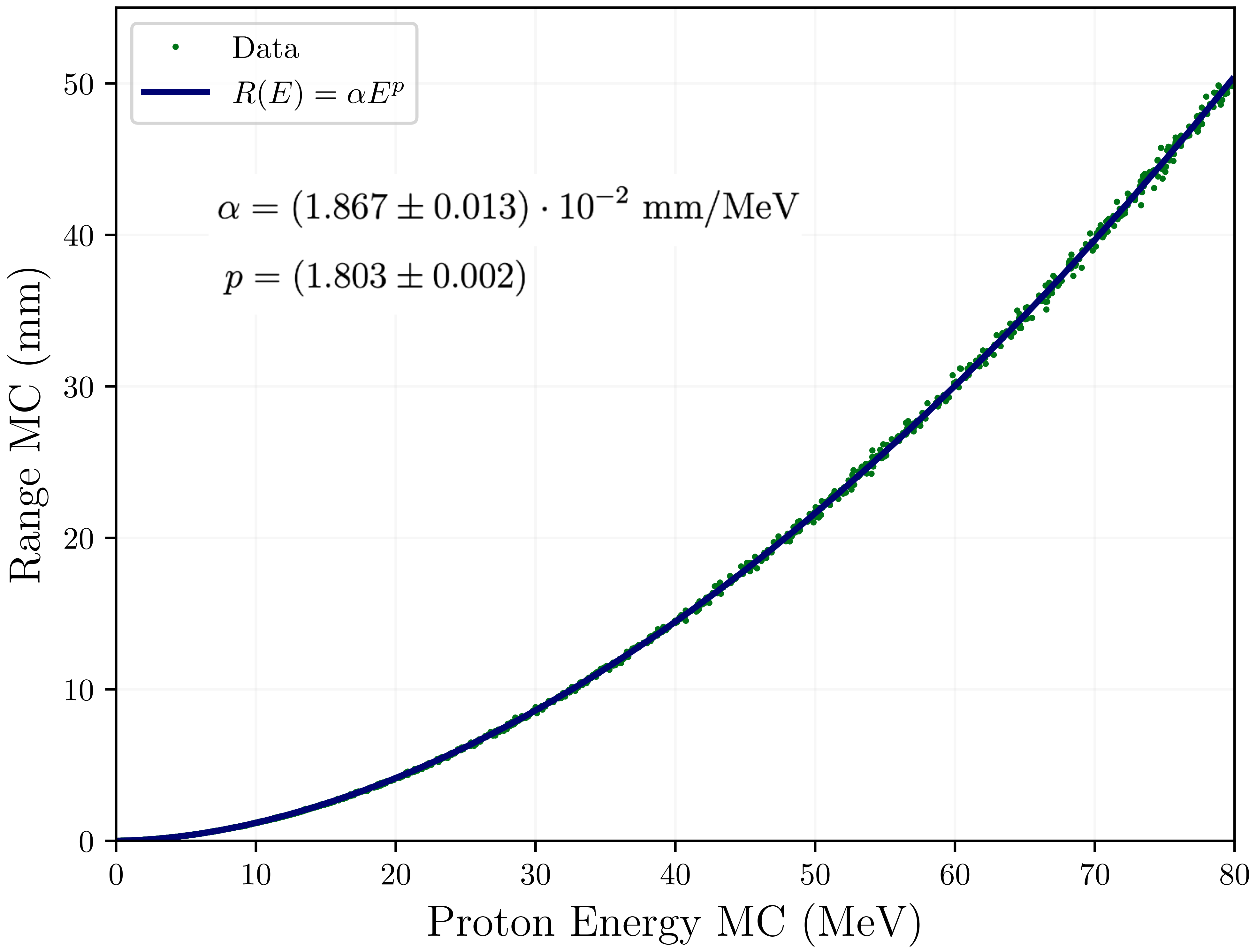
Reconstructed direction compared to MC truth

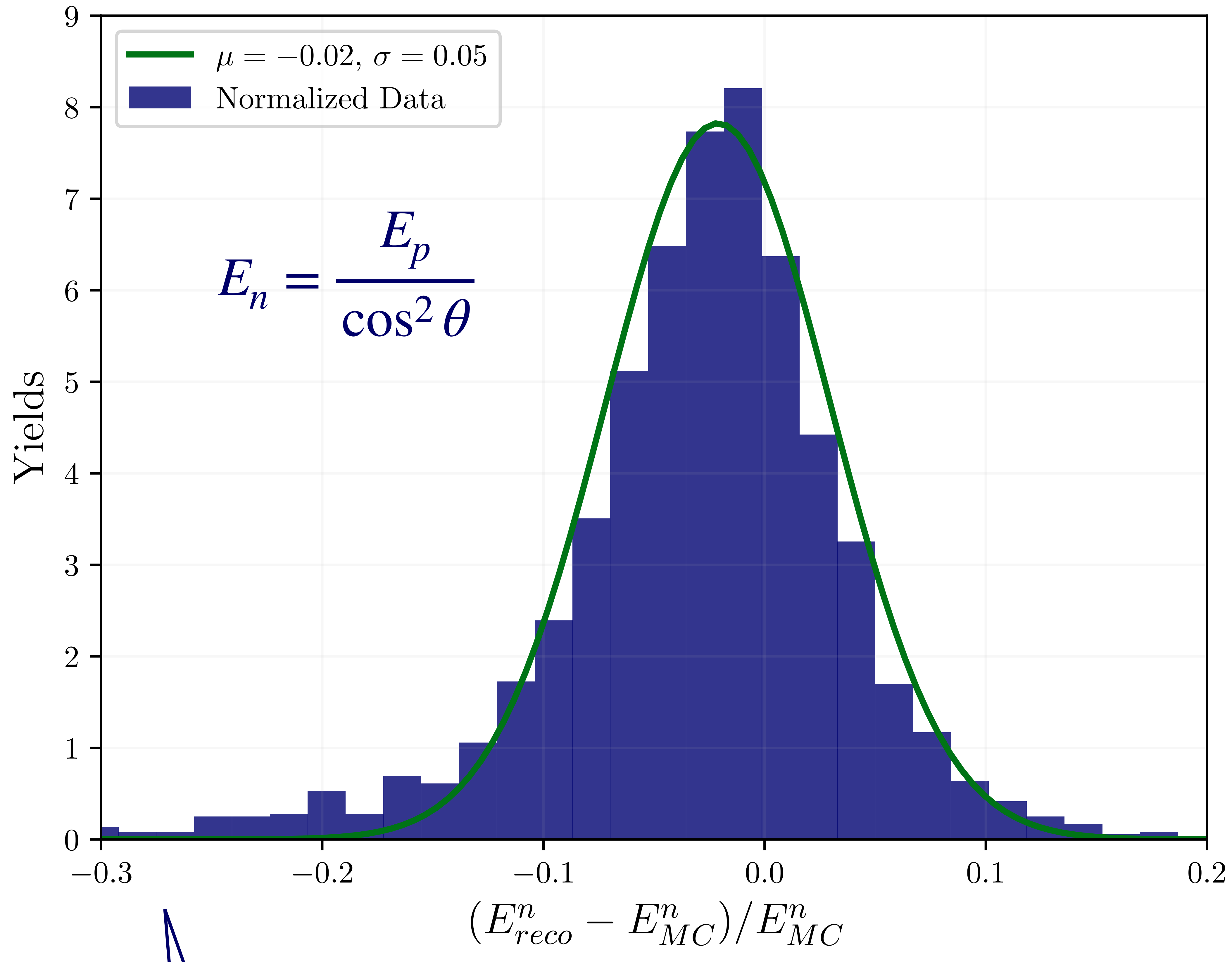
Reconstructed range compared to MC truth



Results

Relationship between proton energy and range based on MC simulations





Reconstructed neutron energy, obtained combining reconstructed proton energy and direction, compared with MC truth

Conclusion & Future developments

The method for measuring the energy and direction of neutrons incident on the scintillator appears promising based on Monte Carlo data when the source position is known

The method relies on various techniques: the Hough transform, the momenta methods, and deep learning techniques to determine the neutron direction and energy from a single scattering event

Applying the same method to double-scattering events would allow for determining not only the incident neutron energy but also the source position when it is unknown

LOOKING FORWARD TO EXPERIMENTAL DATA