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

Cristian Massimi

Department of Physics and Astronomy «Augusto Righi»

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concept

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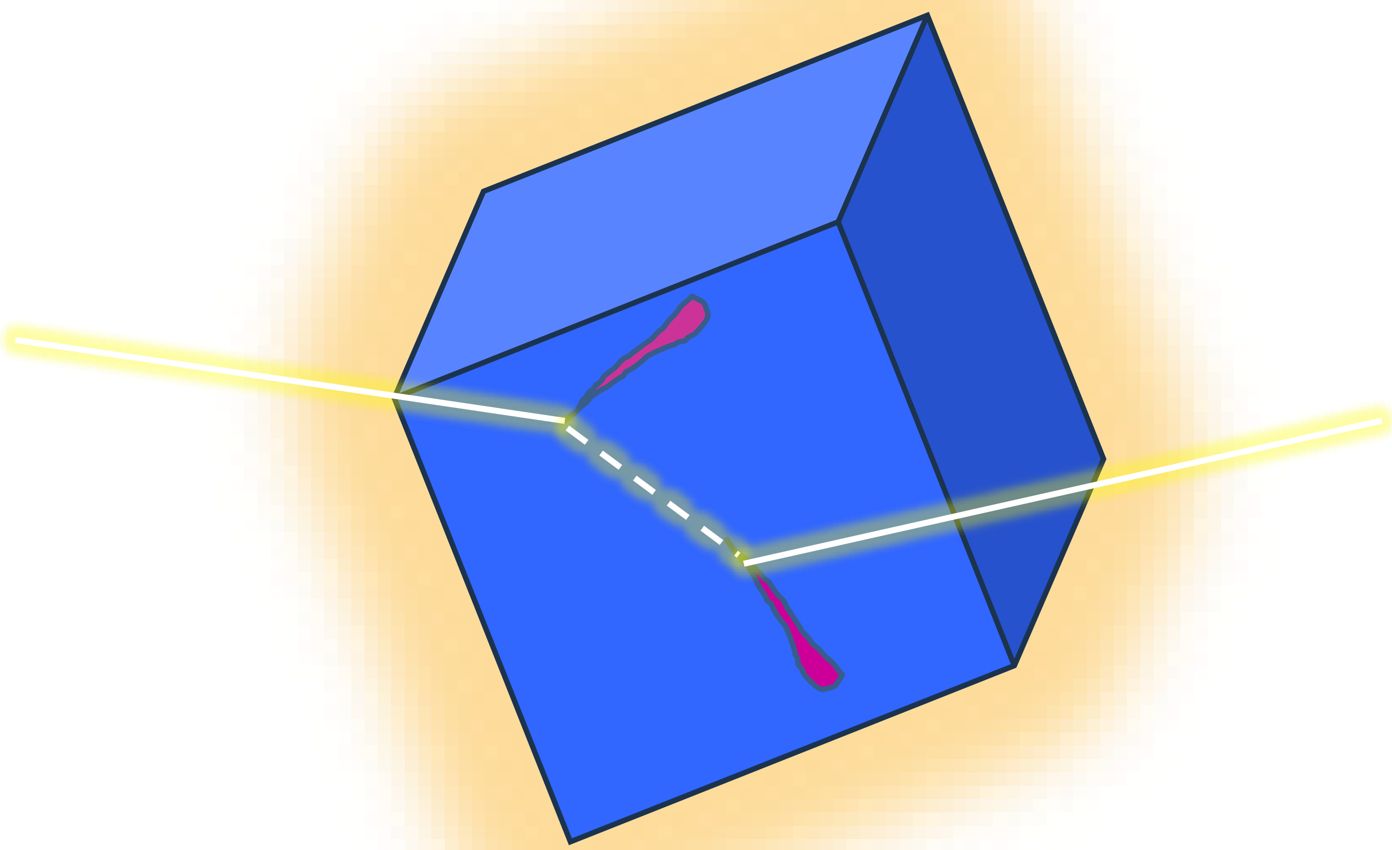
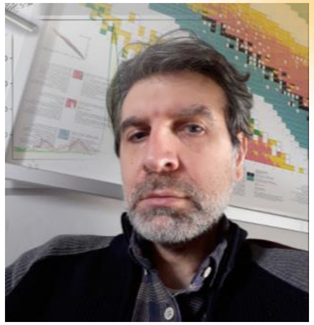
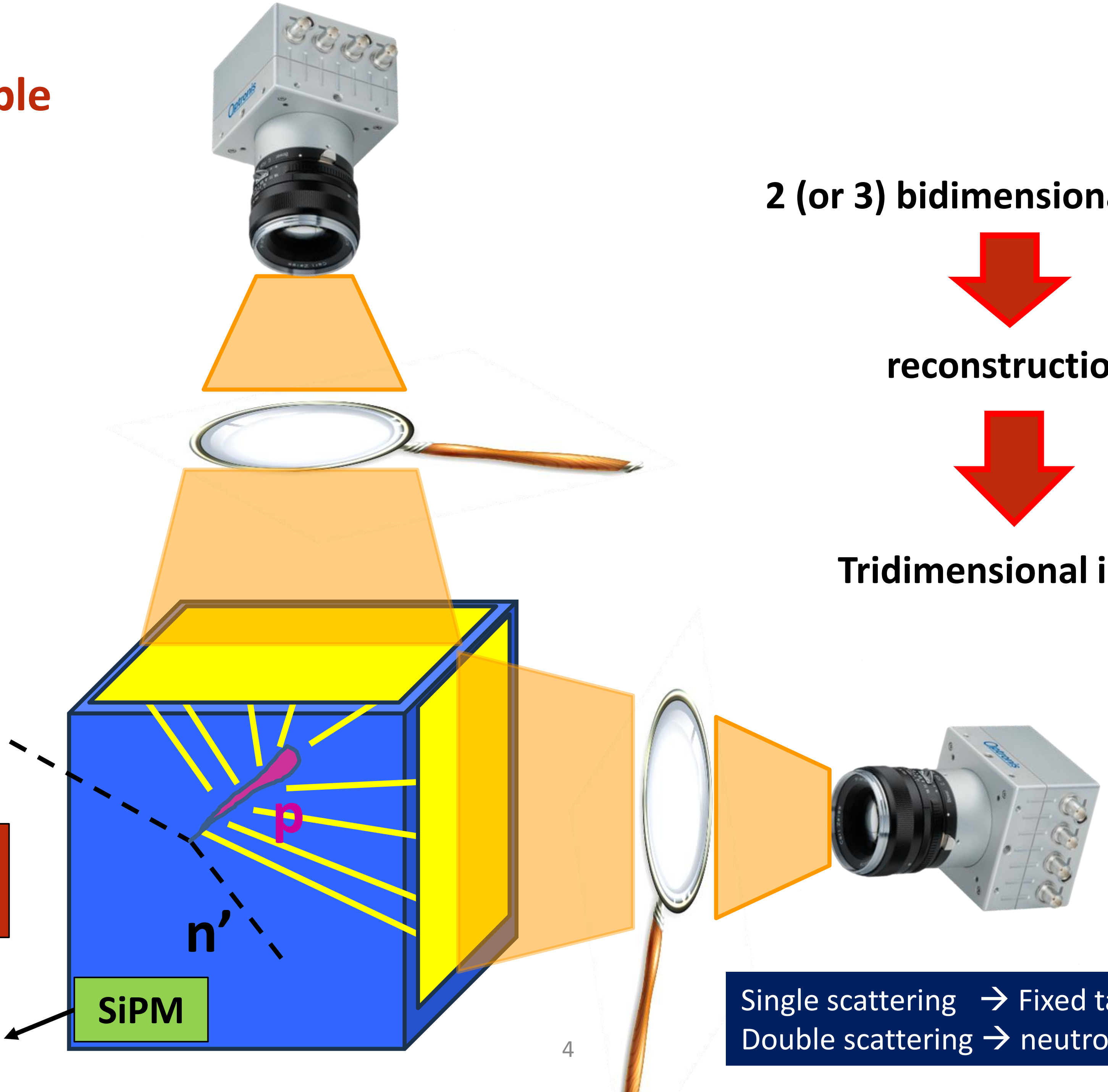
RIPTIDE: Recoil Proton Imaging Detector





Working principle

Optical system



2 (or 3) bidimensional images

reconstruction

Tridimensional image

High frame rate
CMOS

Recoil Proton Technique

Trigger system + ToF

Single scattering → Fixed target exp.
Double scattering → neutron source ?

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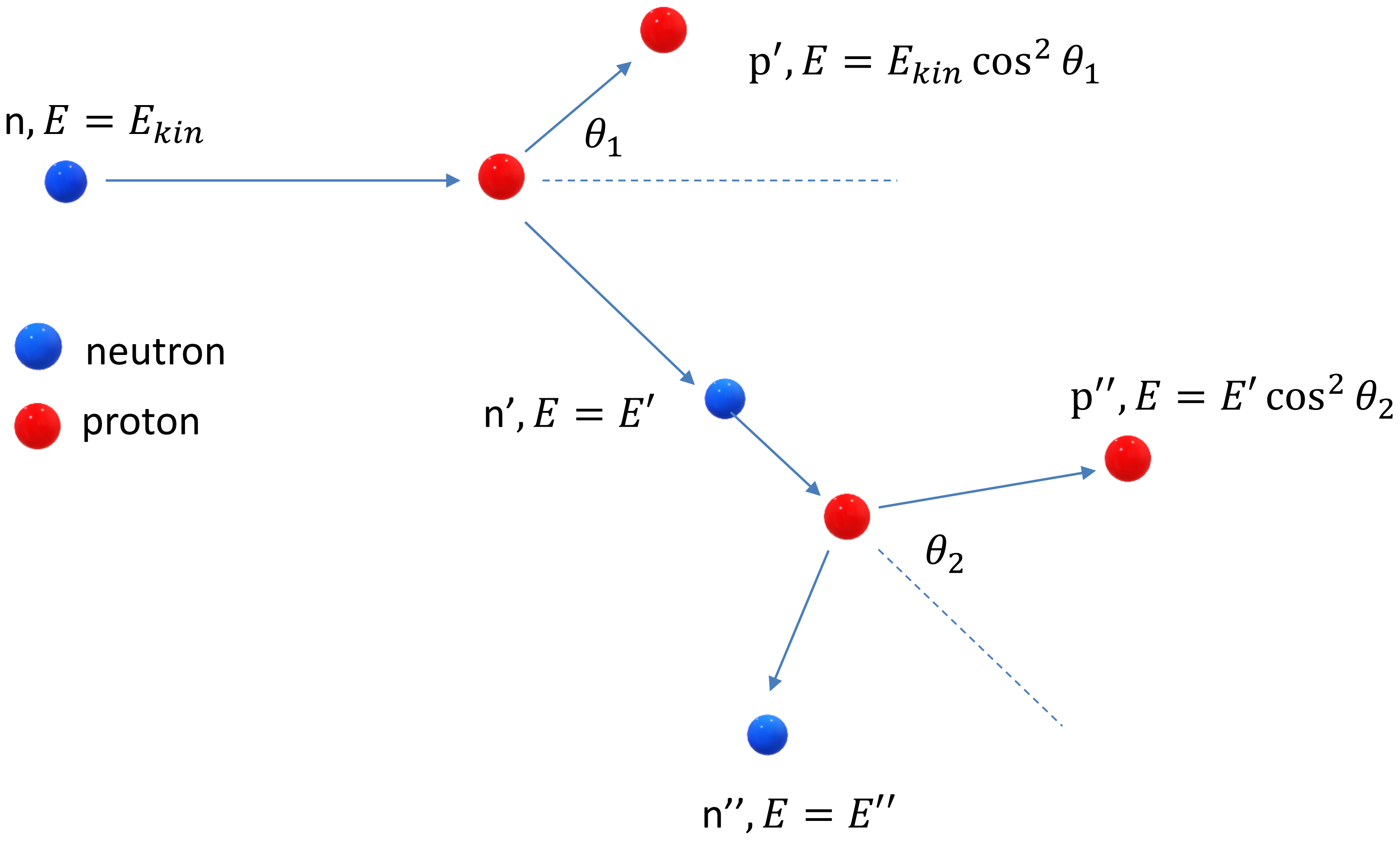
Methodology: Recoil Proton Technique



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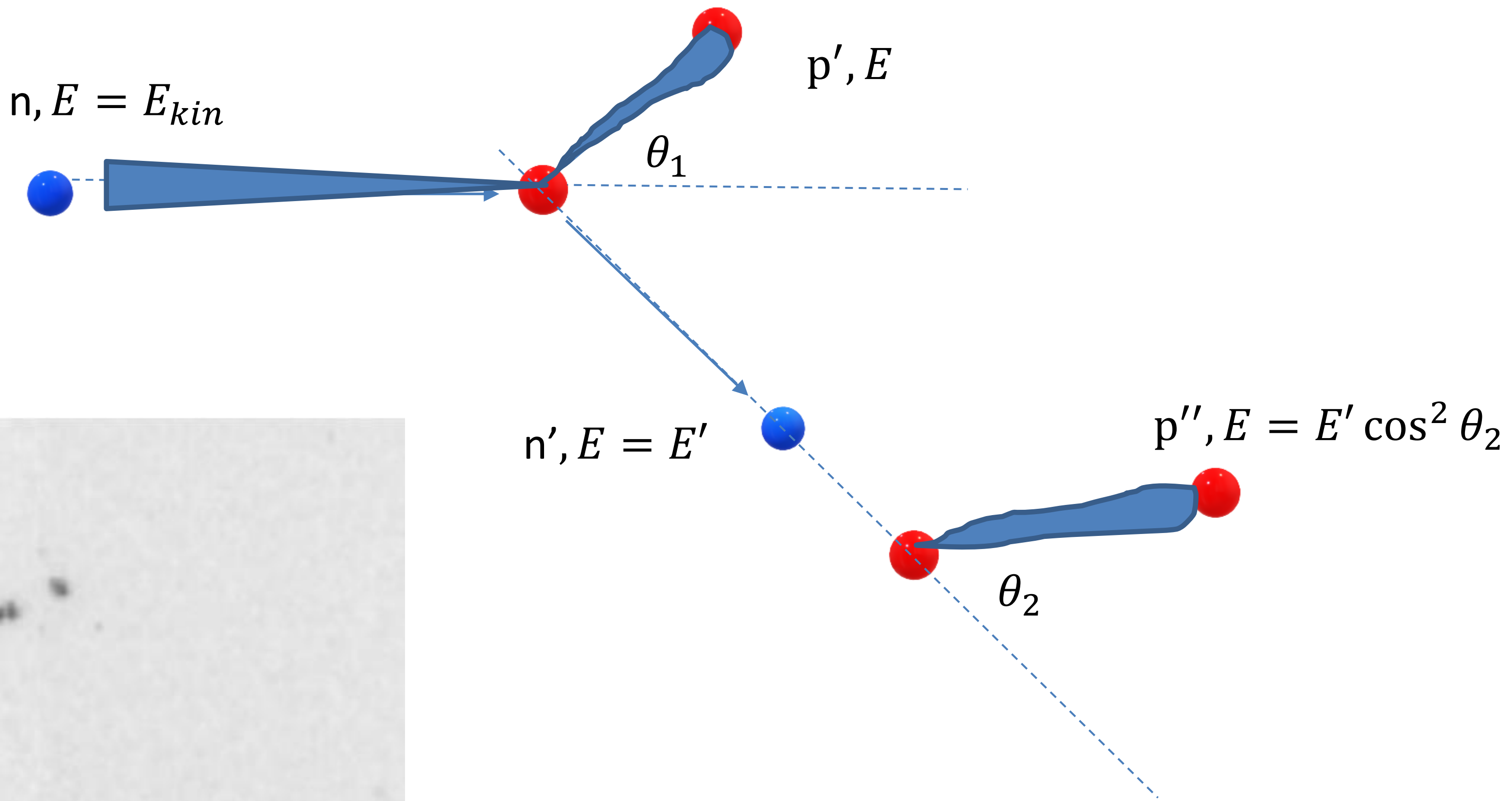
Methodology: Recoil Proton Technique

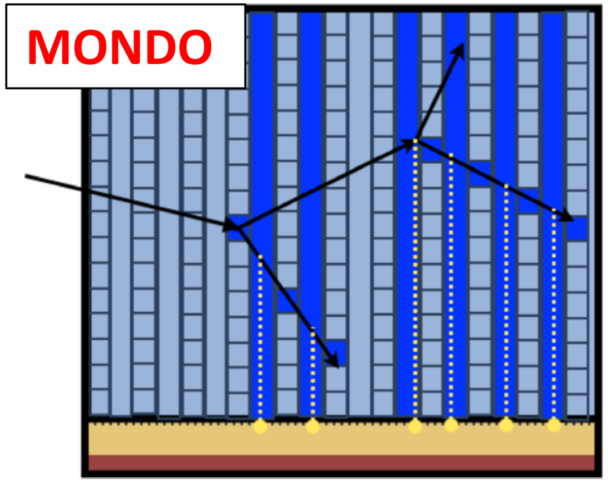


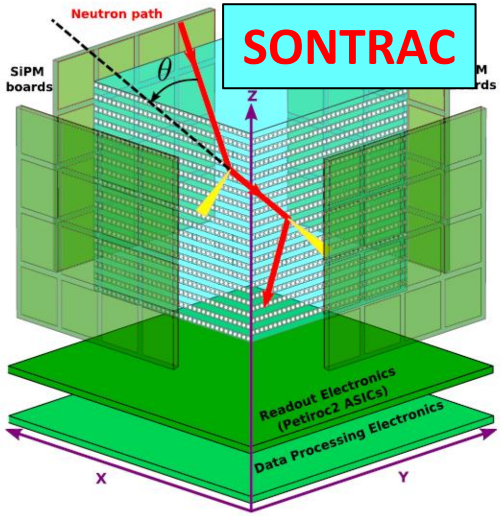
CCD image of a double scatter from a 65 MeV neutron incident from top

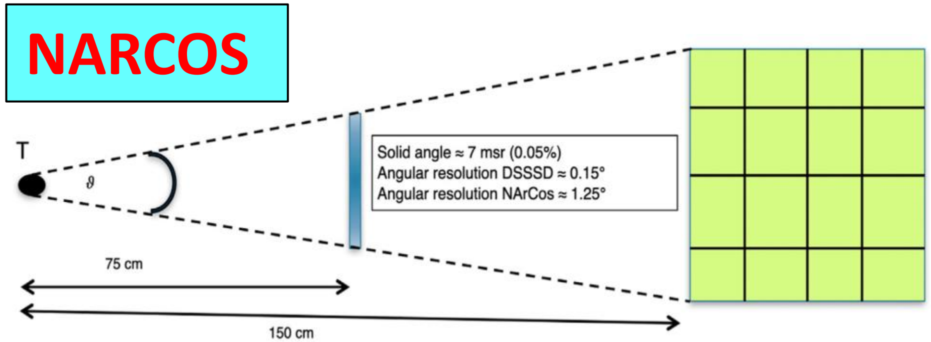
James M. Ryan, et al. «A Scintillating Plastic Fiber Tracking Detector for Neutron and Proton Imaging and Spectroscopy», https://scholars.unh.edu/ssc/208

State of the art

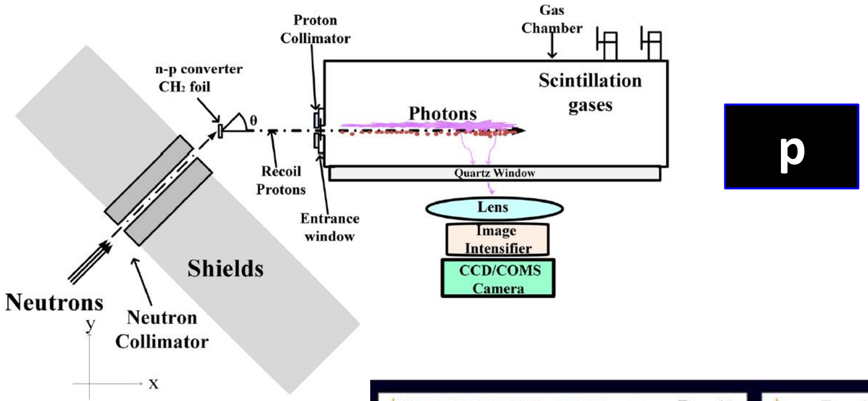
Neutron track Imaging with Single and Double scattering

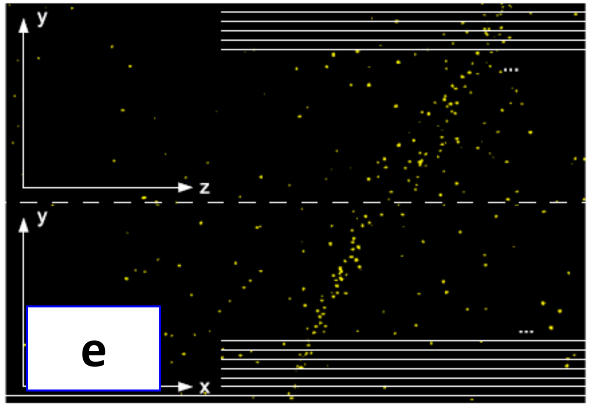




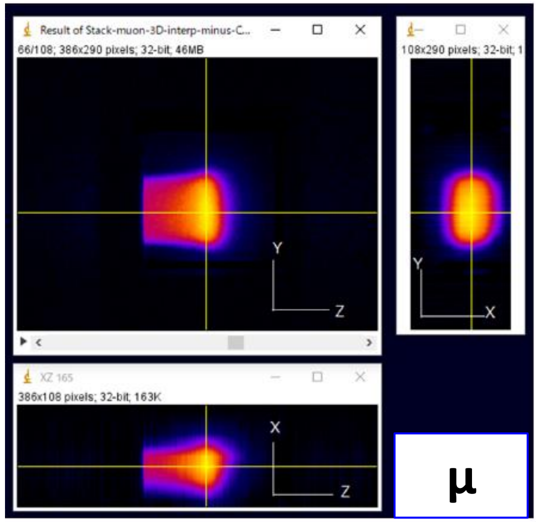


Optic system to «photograph» particles (p, e, μ)





(a)



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

J. Hu et al, Sci. Rep. 8, 13363 (2018)
M. Filipenko et al. Eur. Phys. J. C (2014) 74:3131
S. Yamamoto, et al. NIMA 1015 (2021) 165768

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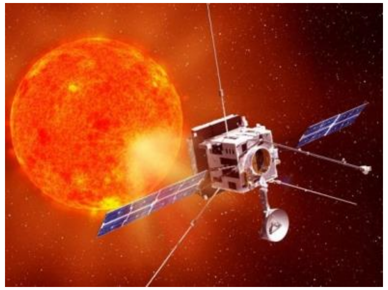
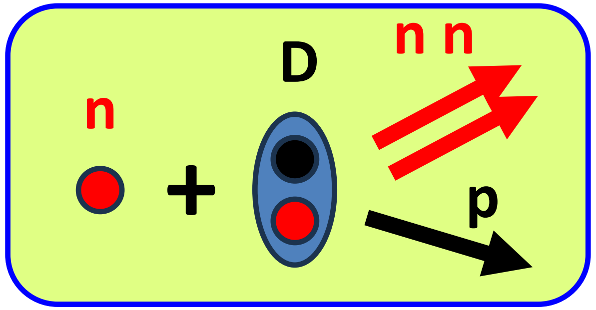
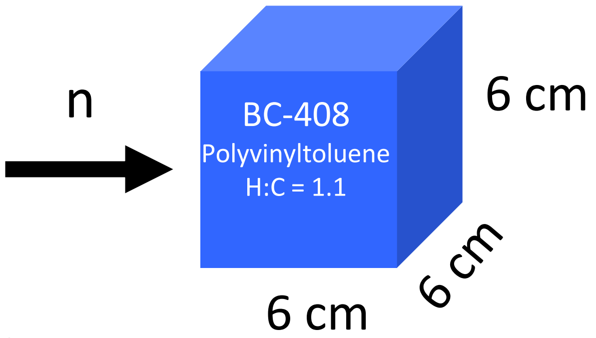
Some applications



Application	Configuration (n. scattering)	Dimensions (cm x cm x cm)	Neutron energy (MeV)	Background	data tacking (duration)	Experimental site
Solar neutrons	Double scattering	5x5x5 (SONTRAC)	10 – 50	Cosmic rays	months	satellite
Space radioprotection	Single scatt. (up – down)	~ 10x10x10	10 – 1000	Secondary particles + γ	weeks	Laboratory
Hadrontherapy radioprotection	Double scattering	10x10x20 (MONDO)	10 – 200	Secondary particles + γ	weeks	Laboratory
Nucl. Phys.: N-N scatt. length	Single scattering	6x6x6	10 – 50	Secondary particles + γ	weeks	Laboratory
Soil moisture	Single scatt. (up – down)	6x6x6	10 - 50	Cosmic rays	months	On the ground
Nucl. Phys.: Rad. beams	Single scattering	10x10x10	< 100	Secondary particles + γ	weeks	Laboratory
…	…	…	…	…	…	…

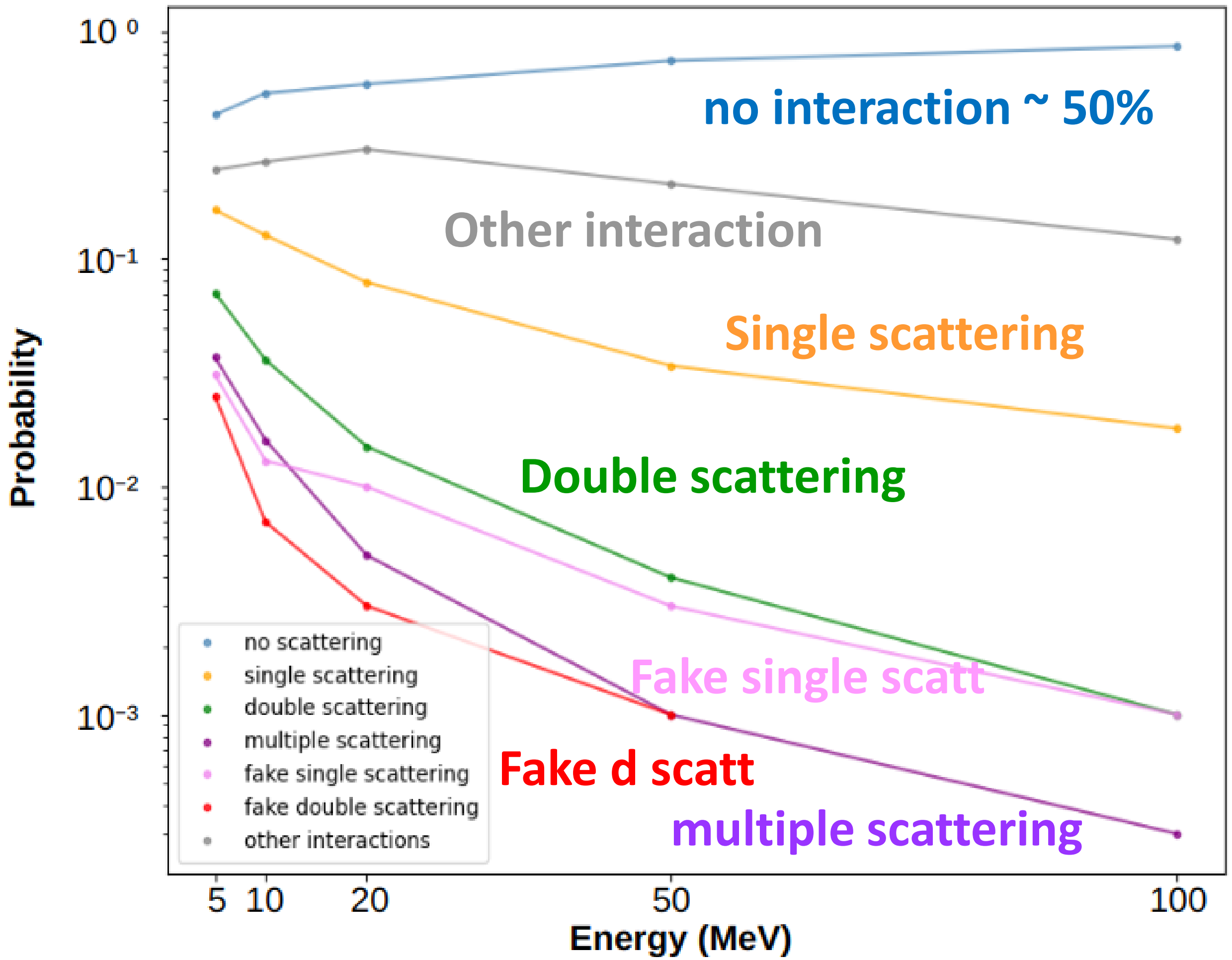


RIPTIDE, so far: Geant4, n + scintillator



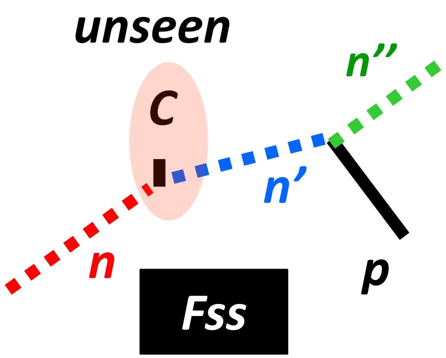
Simulation:

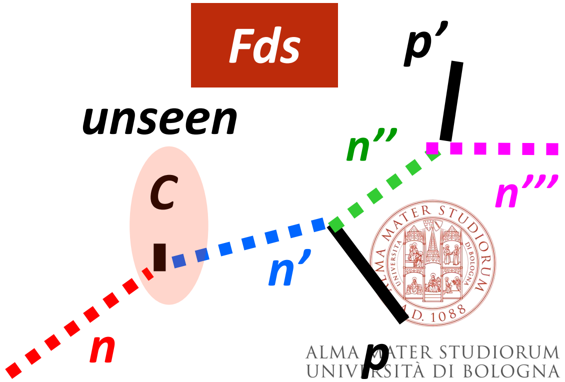
- probability of Single (double) interaction
- Background estimation



- Fss:
  - El. scatt. on C (unseen) and then on p

- Fds:
  - scatt on C (unseen) and then on p and p
  - Scatt on p, on C (unseen) and on p





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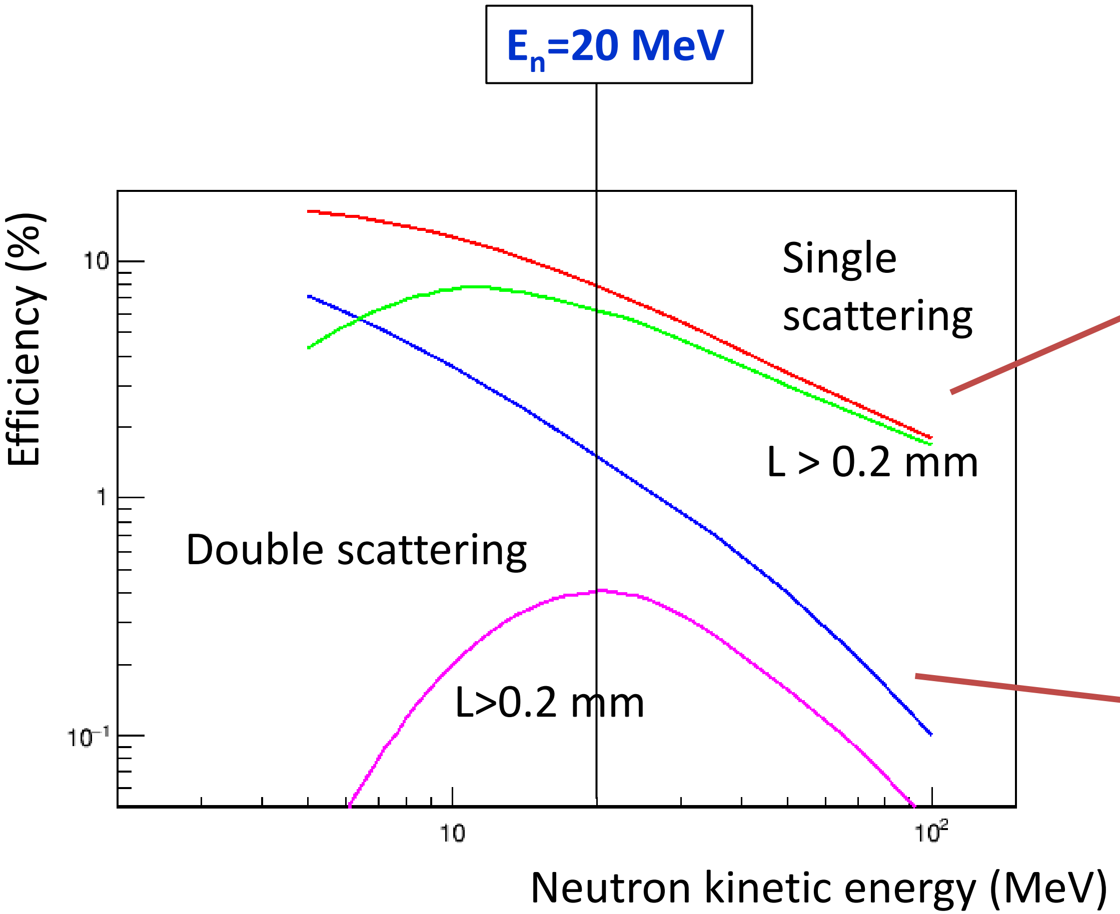
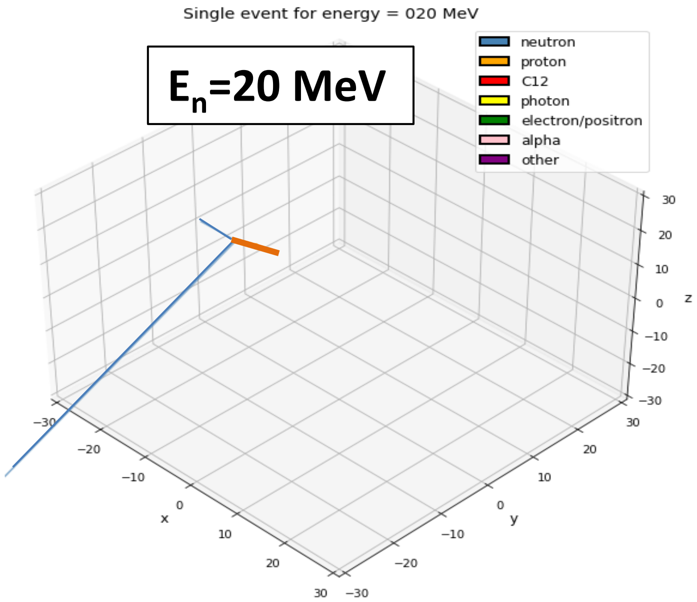
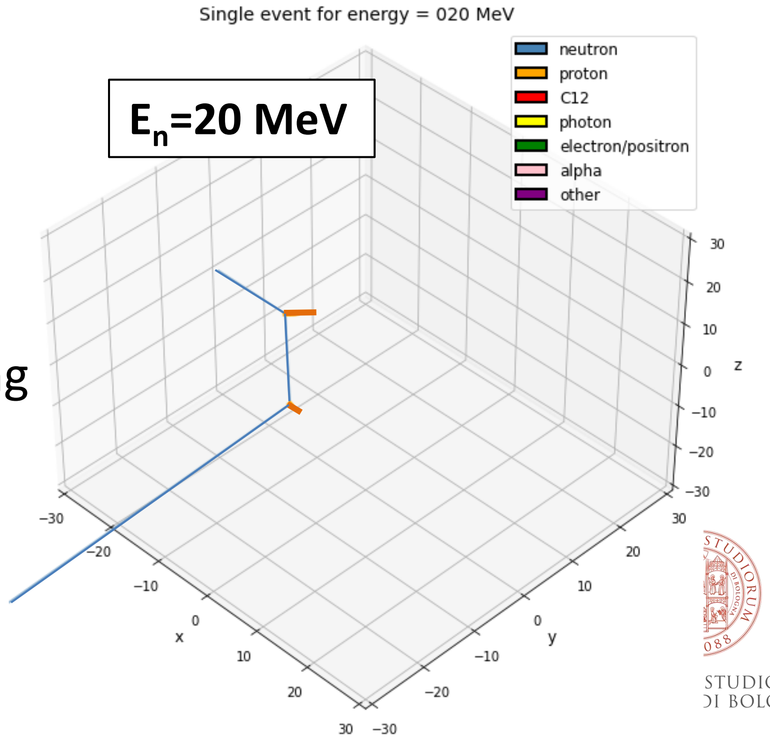
RIPTIDE, so far: Geant4, n + scintillator



Single scattering



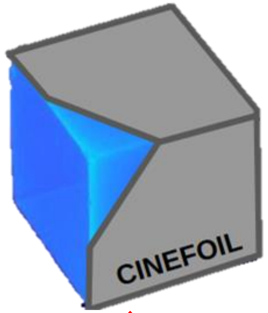
Double scattering

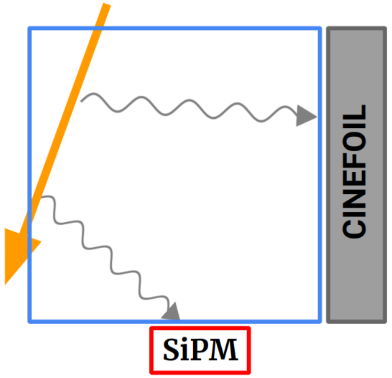


E_n = 20 MeV

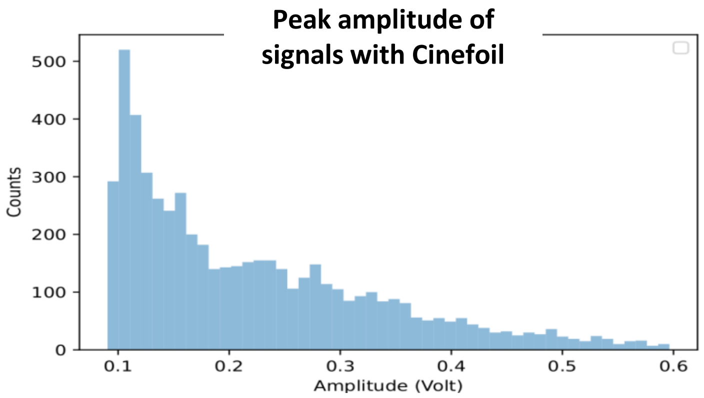
- Single scattering: efficiency ~ 10%
- Double scattering: efficiency ~ 1%

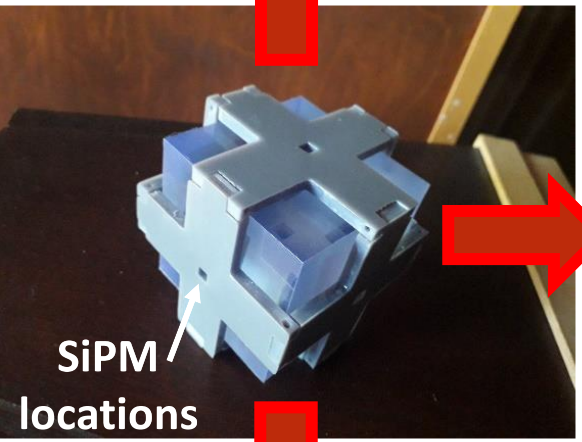
RIPTIDE, so far: SiPM test





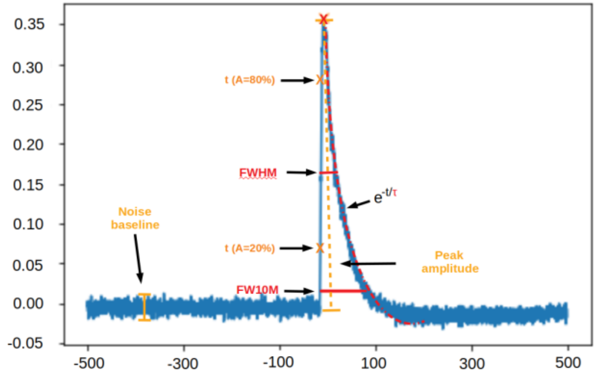
CINEFOIL:
- Only direct light
- Lower signal
- Better time resolution

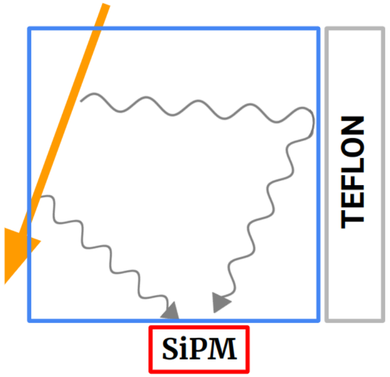




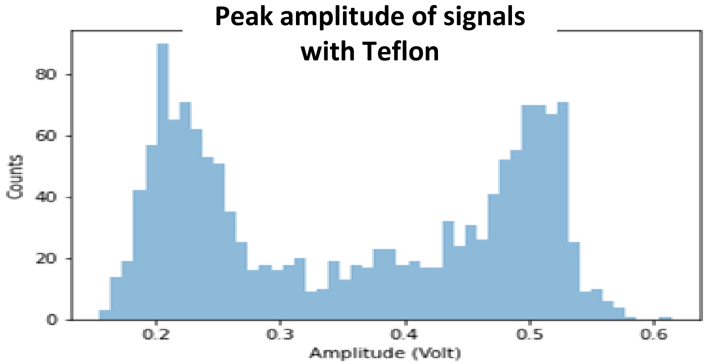
With or without amplifier?

	Risetime (ns)	Decay time (ns)	FWHM (ns)	FW10M (ns)
CNA	3 ± 1	39 ± 4	150 ± 40	490 ± 80
CA	3 ± 1	39 ± 4	160 ± 40	490 ± 60
TNA	6 ± 3	42 ± 6	230 ± 30	530 ± 90
TA	5 ± 3	60 ± 15	310 ± 70	700 ± 130

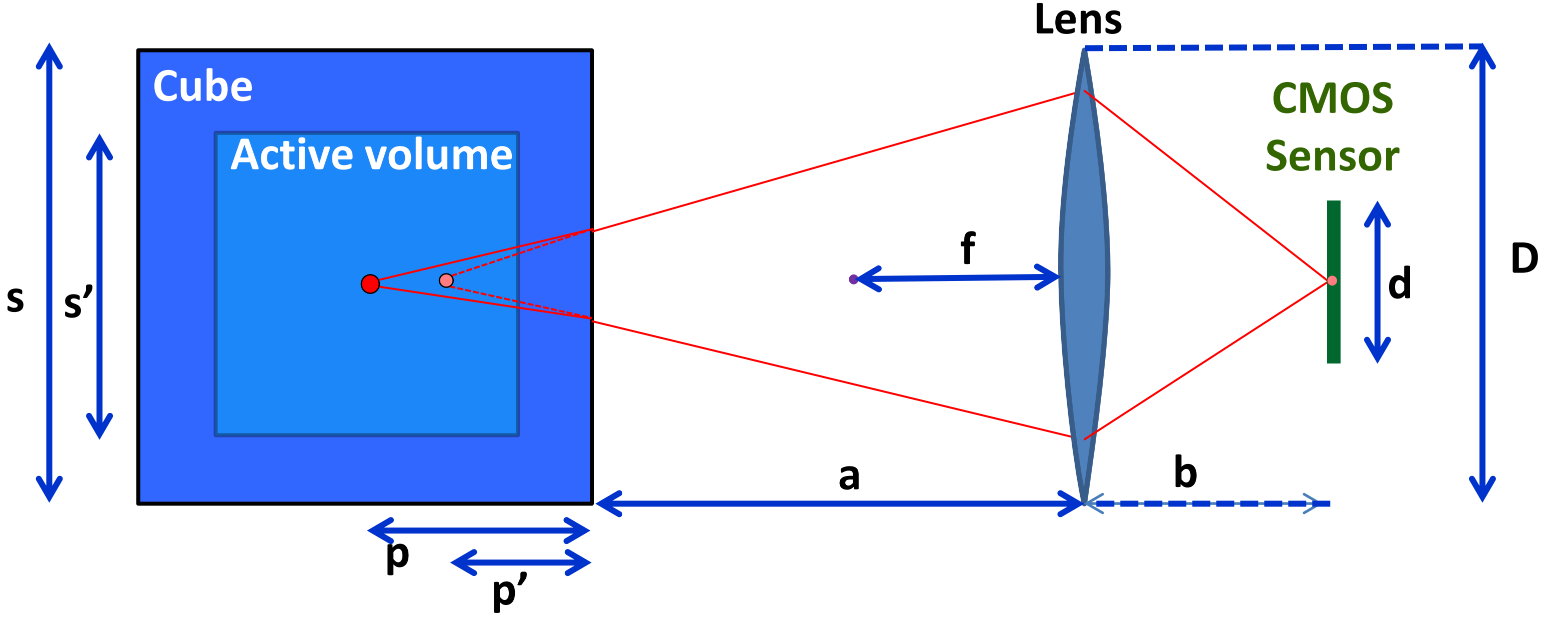




TEFLON:
- Direct and indirect light
- higher signal
- Worsen time resolution

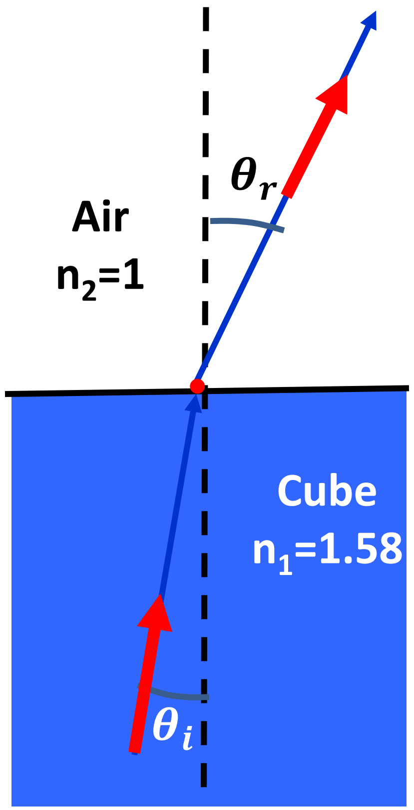


RIPTIDE, so far: optic system simulation



$$\sin\theta_r = \frac{n_1}{n_2}\sin\theta_i$$

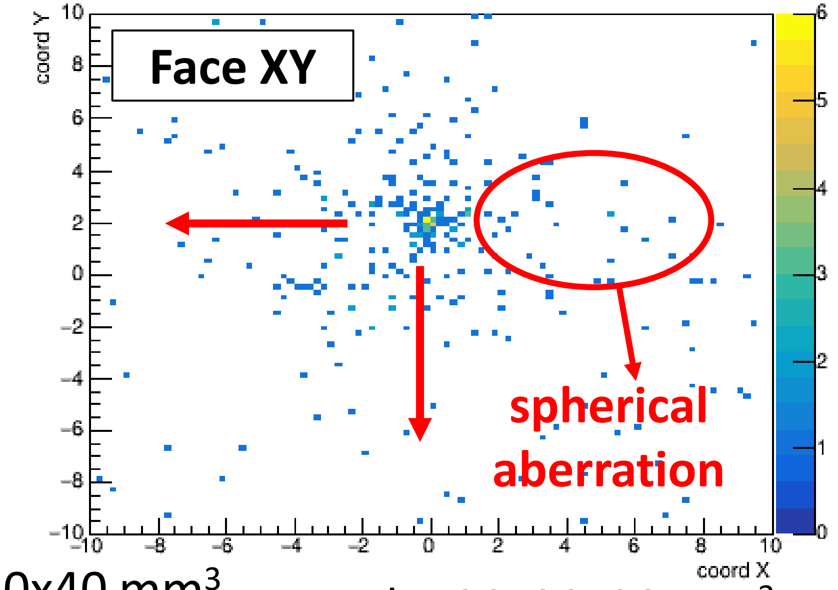
$$\theta_{max} = 39,3°$$

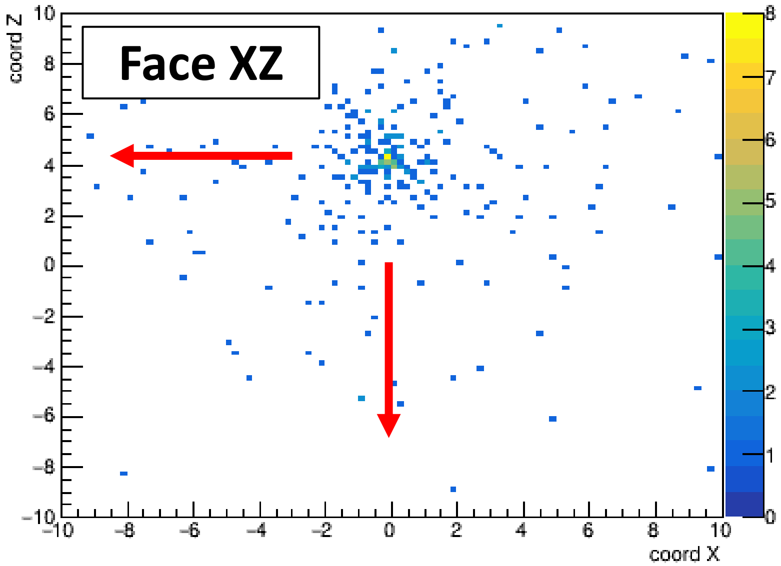


- Snell law → 67% photons
- Polarization → 95% photons to sensor
- Aberration

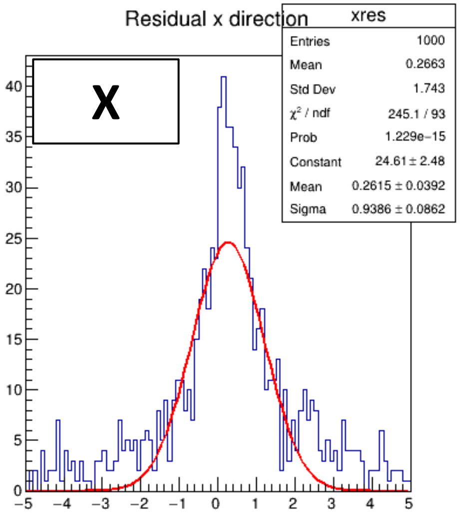
RIPTIDE, so far: optic system simulation

- Pointlike sources in the cube
- Isotropic direction
- # of photons: 6.88×10^4
- Equivalent to 6.88 MeV p



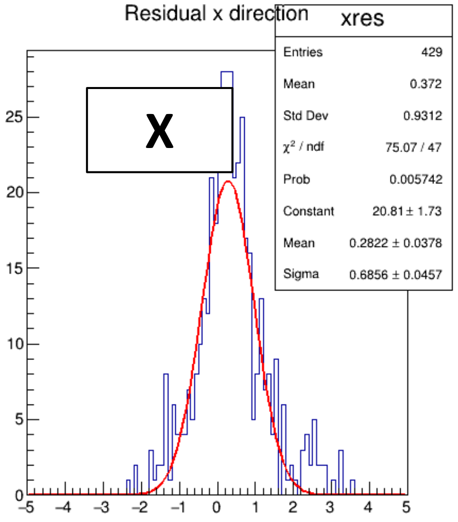


Cube 53x53x53 mm^3



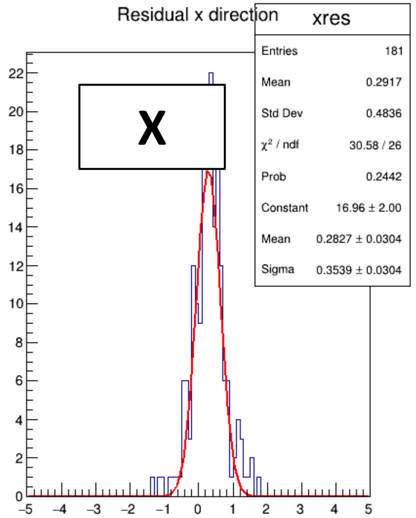
Residuals 0.96 mm

Cube 40x40x40 mm^3



Residuals 0.68 mm

cube 30x30x30 mm^3



Residuals 0.35 mm

Decreasing ACTIVE Cube dimension
- improve Position Precision
- decrease detector efficiency

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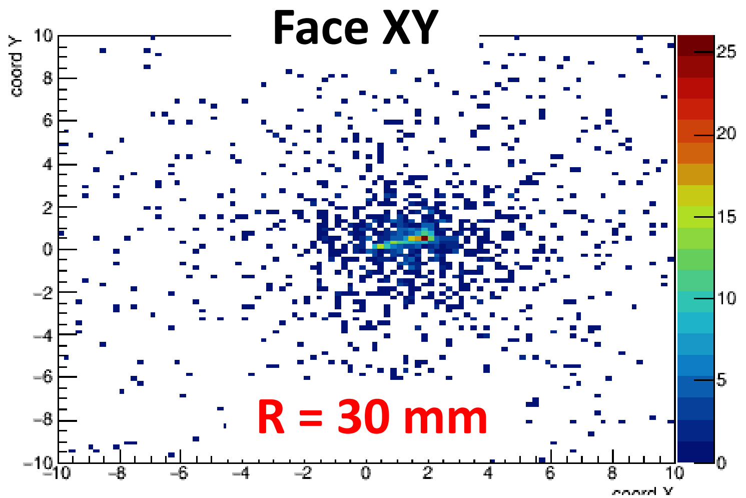
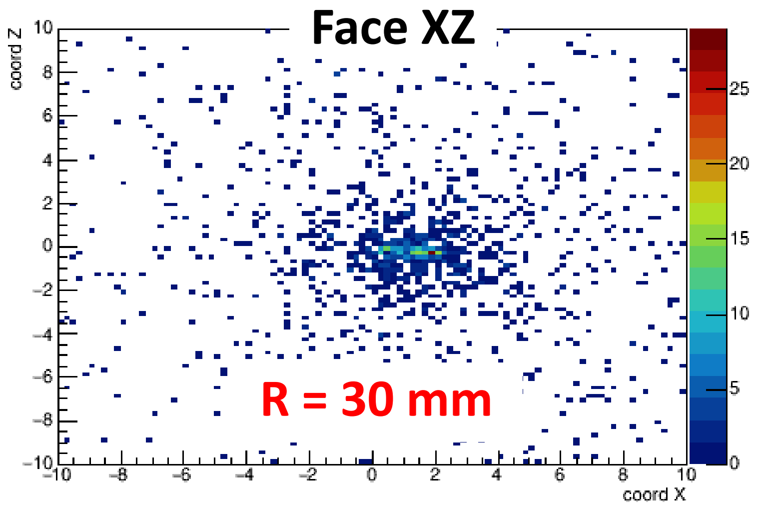
RIPTIDE, so far: optic system simulation with Geant4

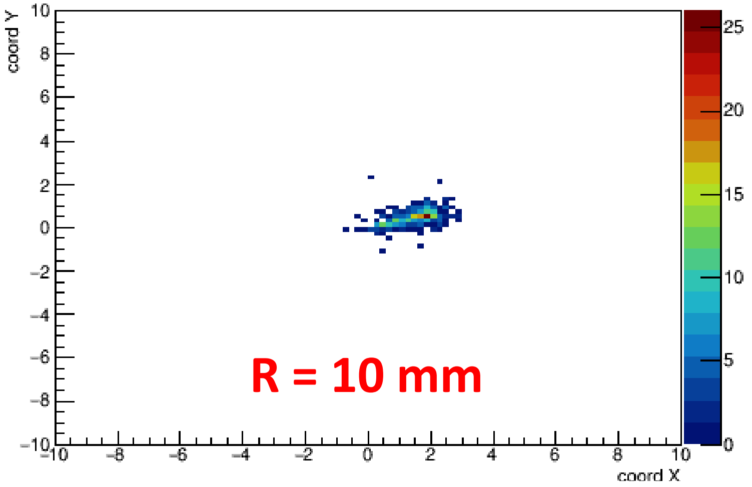




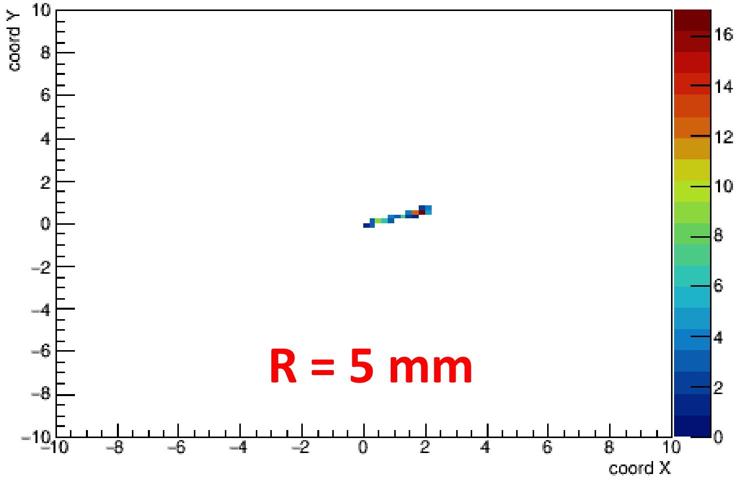
~ 1440 photons/view

PROTONS

- Cilindric source
- Isotropic direction and position
- Energy: 30 MeV
- 10 k photons per MeV
- p/f=3, f = 30 mm



~ 340 photons/view



~ 80 photons/view

Decreasing the radius of the lens

- spherical aberration → ok
- Background → ok
- light yield → ko

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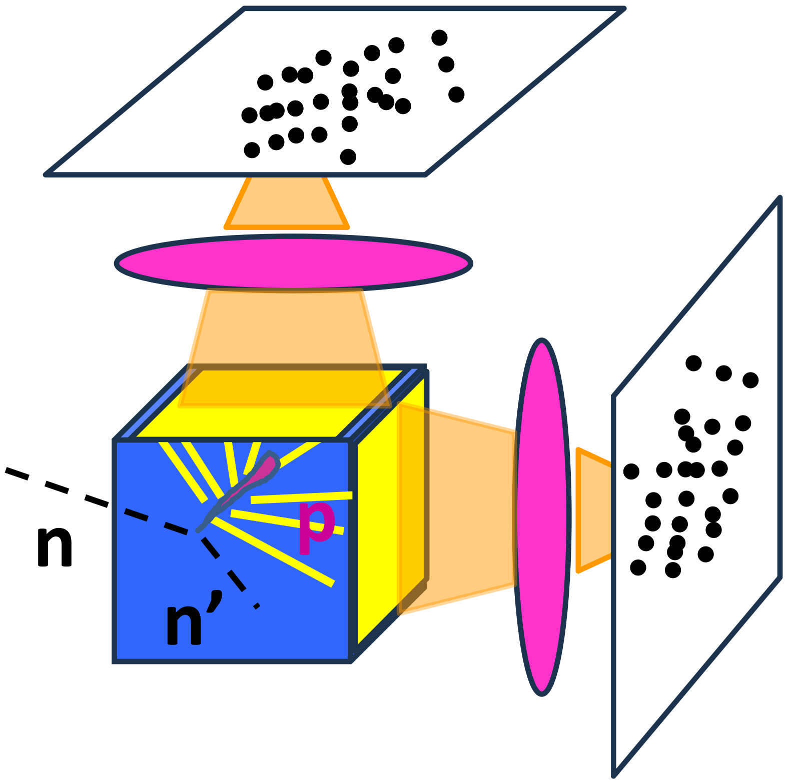
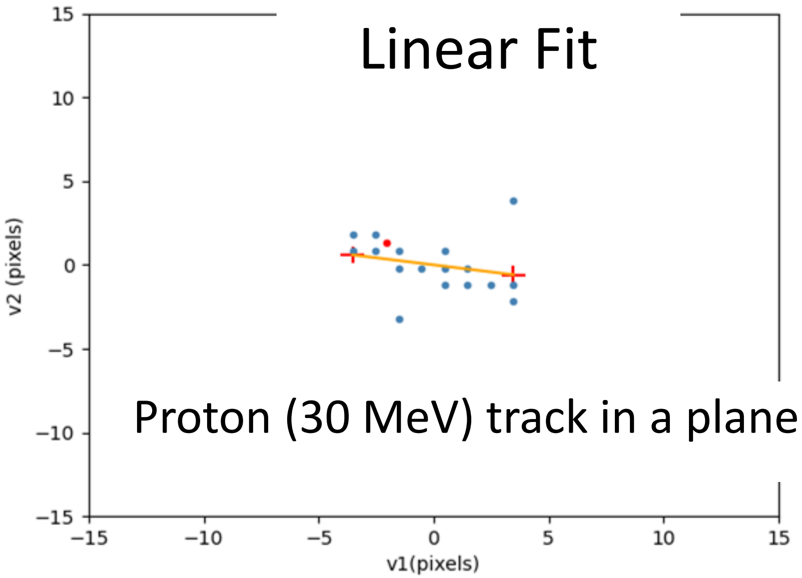
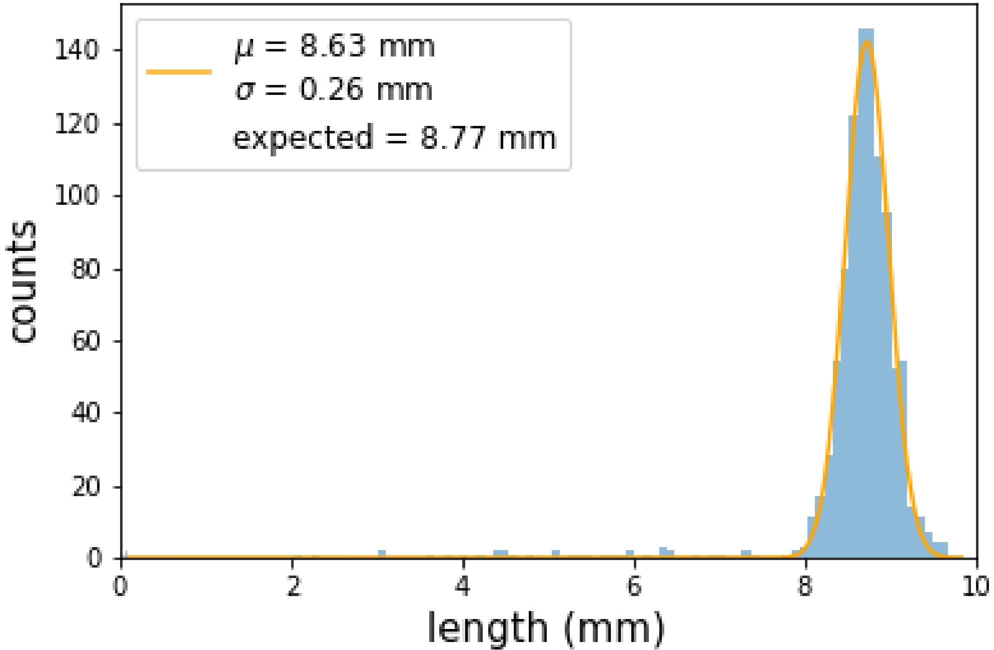
RIPTIDE, so far: track reconstruction algorithms - 1/2





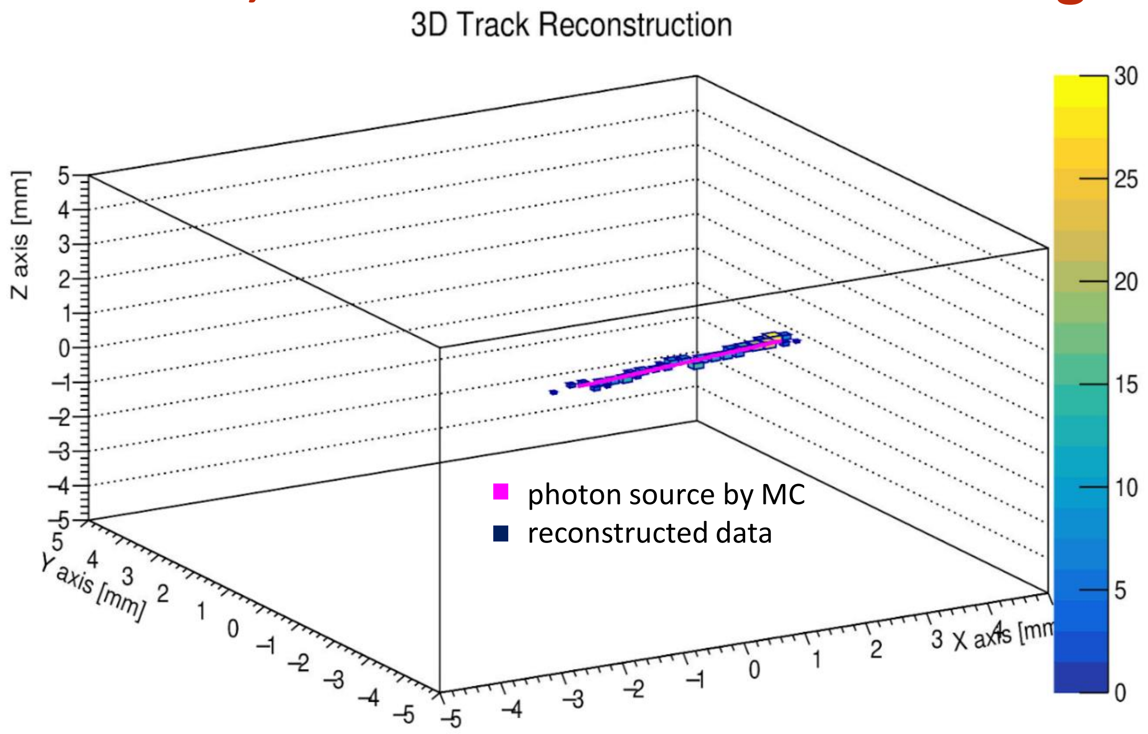
R = 0.5 cm

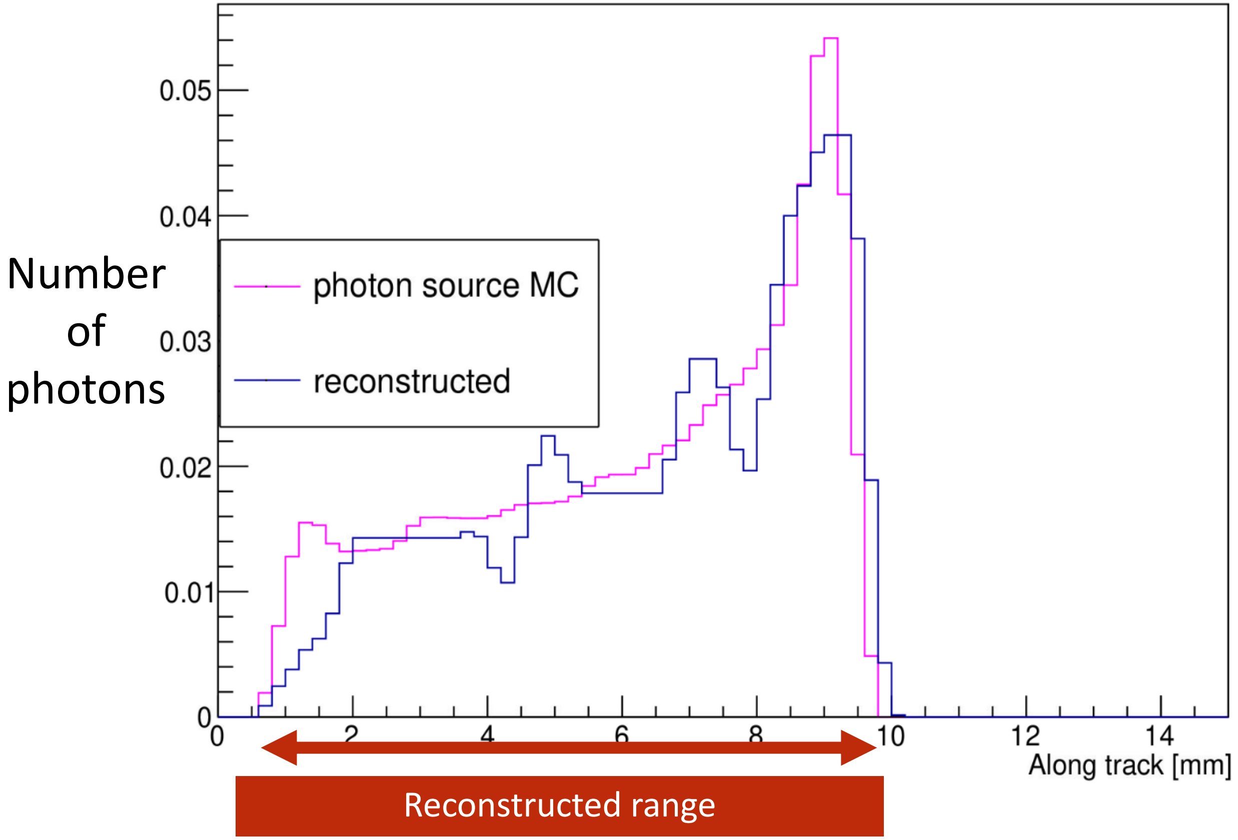
CMOS pixel: 100x100



Track length precision 5%

RIPTIDE, so far: track reconstruction algorithms - 2/2, PCA





Source: 30 MeV protons

- Generated in (2x2x2)cm^3 cube inside detector
- Isotropic direction

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Summary and Conclusion

Studied:

- GEANT4 Simulation
  - p+BC408
  - n+BC408
  - Optical photon transport
- MC of a simple Optical System
  - Systematics of optical parameters
  - Point-like source
  - (Extended, i.e.) proton source
- Track Reconstruction
  - Point interpolation
  - Principal Component Analysis

Challenge:

- **Optical system**
  - Small aberration
  - High light collection
- **System geometry**
  - compact detector
- **Prototype**
  - scintillation light photograph
  - Benchmarking of MC simulation
- **Track reconstruction**
  - Double scattering
  - New methods (AI)

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Cristian Massimi

Department of Physics and Astronomy «Augusto Righi»

cristian.massimi@unibo.it

Backup

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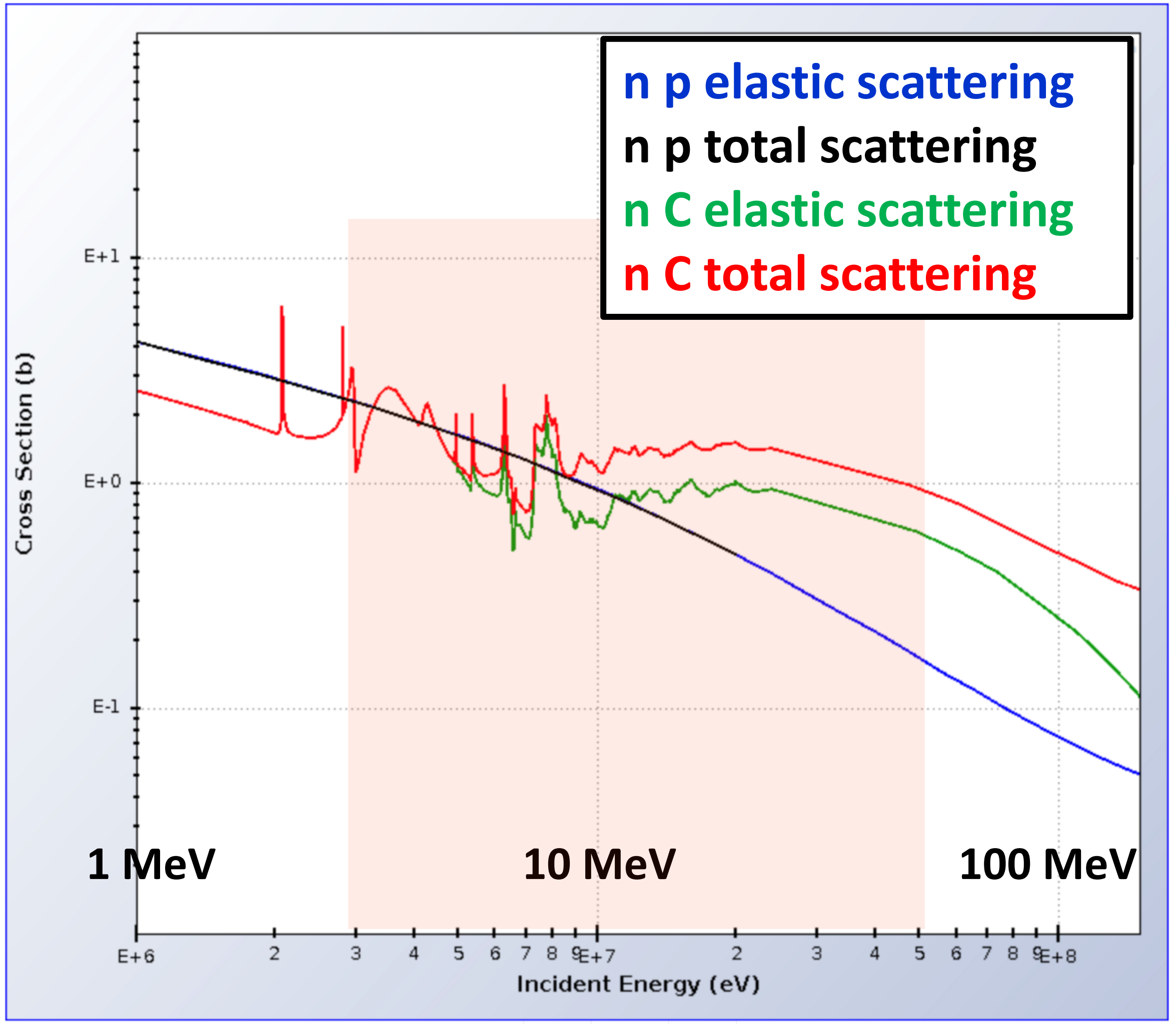
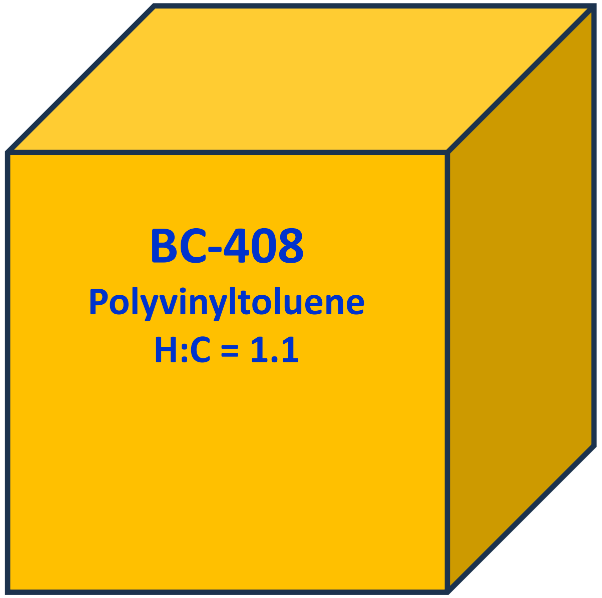
n in a plastic scintillator





Detection volume: (6 cm)^3

neutron energies: 3-50 MeV

proton ranges: 0.2 – 30 mm

H:C = 1.1

- **n p is only elastic (at this energy)**
- **σ(n C) > σ(n p) → large bkg events?**

20

proton (A = Z = 1)

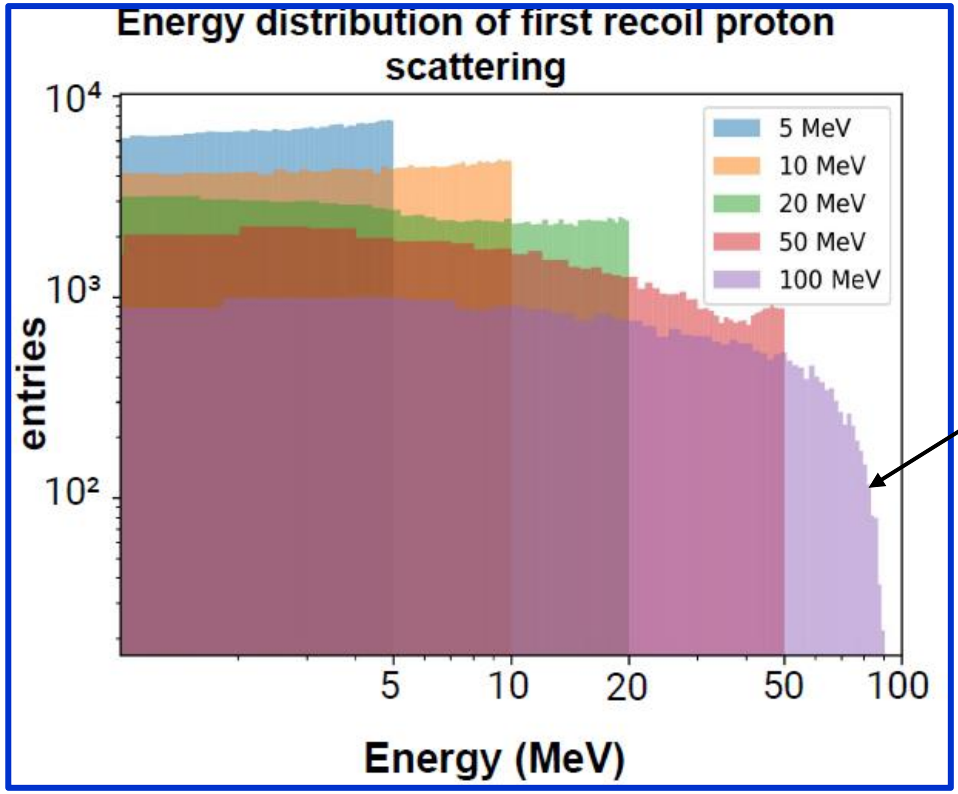
$0 < E_p < E_0$

$$0 < E < \left(1 - \frac{(A-1)^2}{(A+1)^2}\right) E_0$$

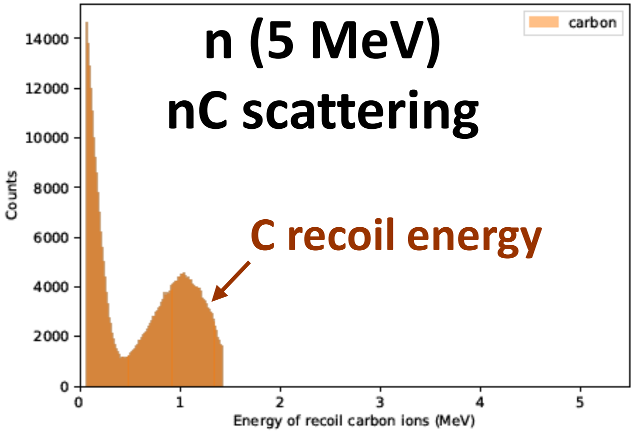
carbon (A = 12, Z = 6)

$0 < E_c < 0.28\ E_0$

n p Single scattering

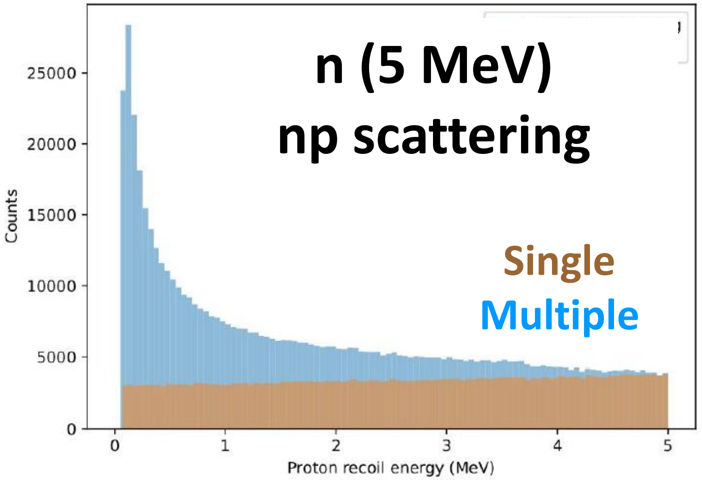


n C
Single scatt



p escape from the scintillator

n p
Single – Multiple scatt



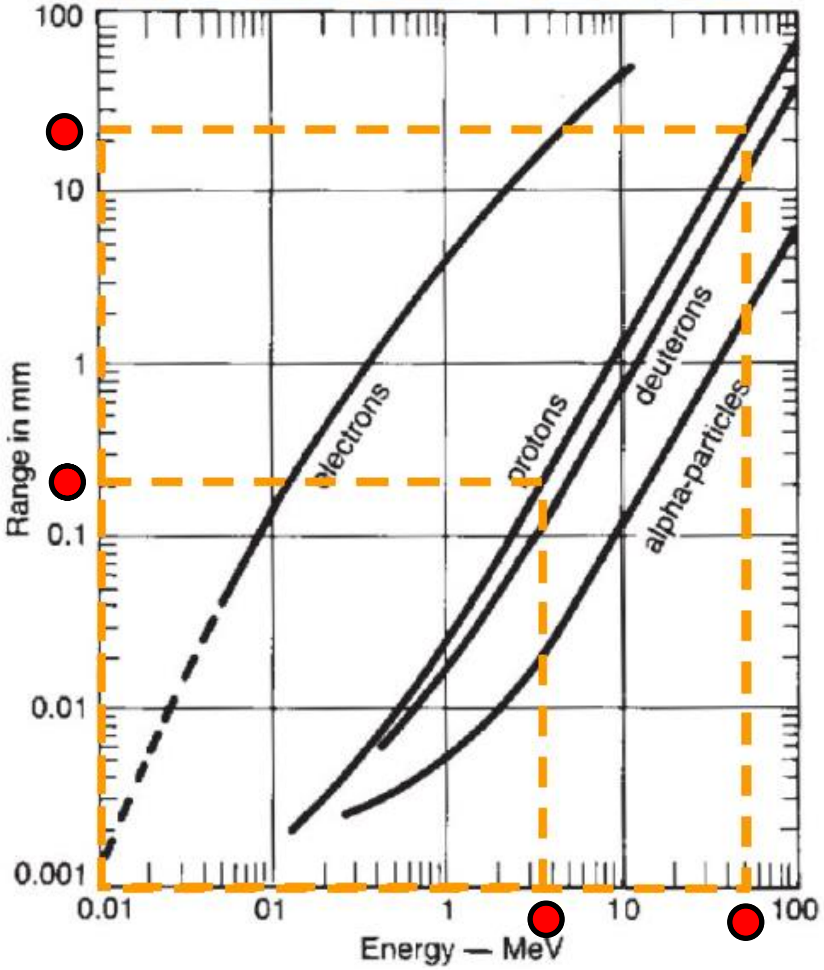
consequence

p & C Range

$$R(E) = \alpha E^p$$

α depends on material
p on Energy (~ 1.75)

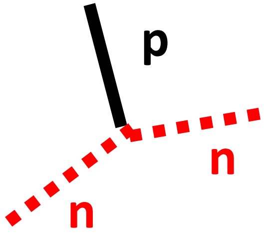
Range in plastic scintillator

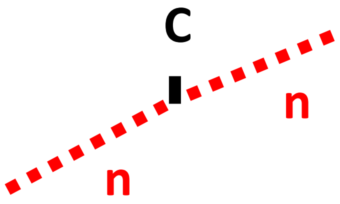


$$R_a(v) = \frac{m_a z_b^2}{m_b z_a^2} R_b(v)$$

a → carbon
b → proton
v→ energy

n at 60 MeV
- **R_p = 35 mm**
- **R_c = 1.5 mm**





Carbon range → 0 (lighted points)
signal below thereshold

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