Detection of explosive materials with Gamma Resonant Nuclear Absorption and Argon-Nitrogen TPC

M. Zeller, I. Badhrees, S. Delaquis, A. Ereditato, S. Janos, I. Kreslo, M. Messina, U. Moser, B. Rossi

Presented by Dr. Igor Kreslo,
Albert Einstein Center for Fundamental Physics,
LHEP, University of Bern

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

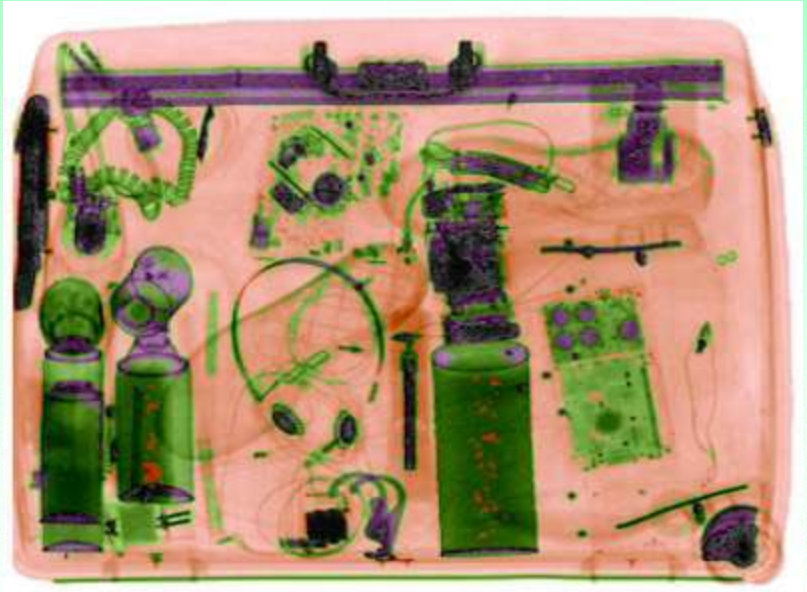
Detection of explosive materials with Gamma Resonant Nuclear Absorption and Argon-Nitrogen TPC

- Motivation
- GRNA radiography and its history
- Time Projection Chamber with liquid Argon-Nitrogen

Multi-energy X-ray cargo radiography – can still something be hidden?

Sensitive to:

Metal objects
High density objects
Characteristic shapes



Not very sensitive to:

Specific chemical composition (Nitrogen)
2D shaped objects (sheet explosives)

Gamma Nuclear Resonant Absorption of ^{14}N

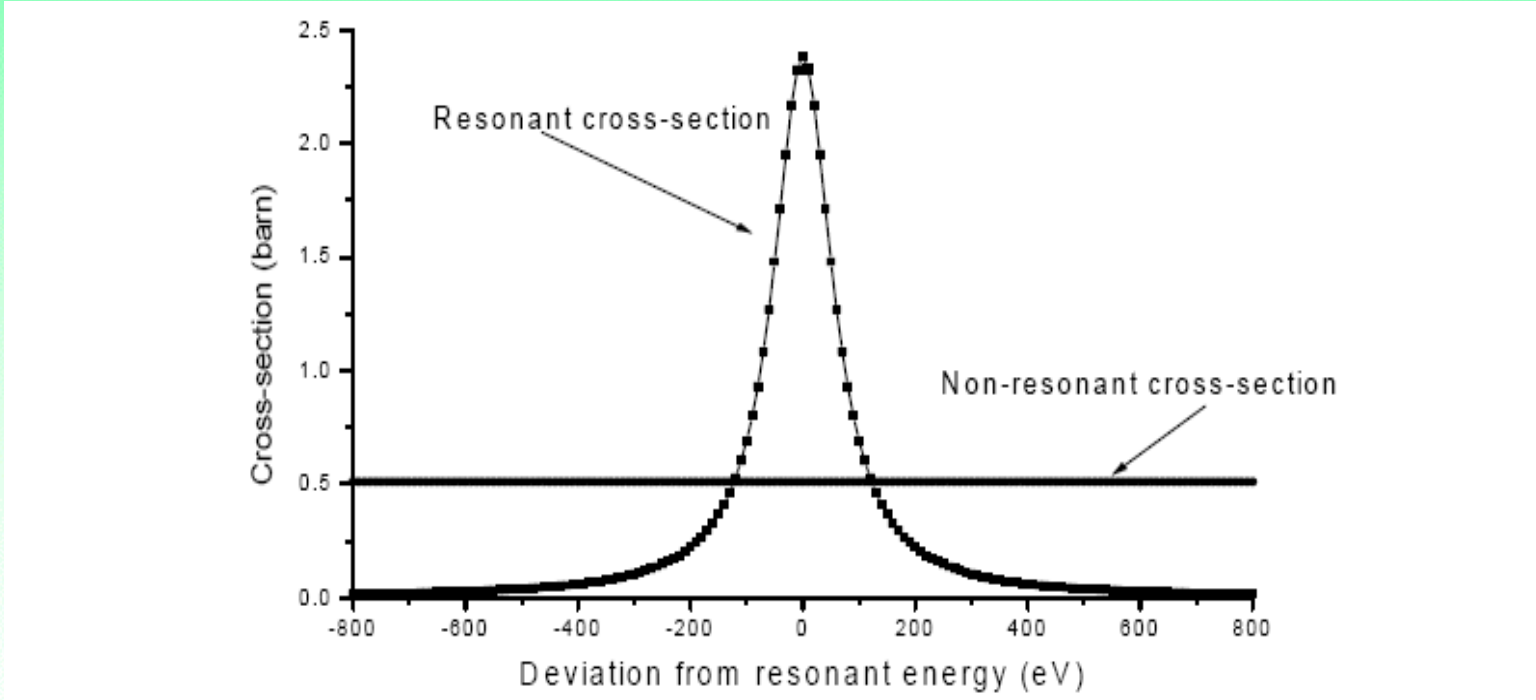
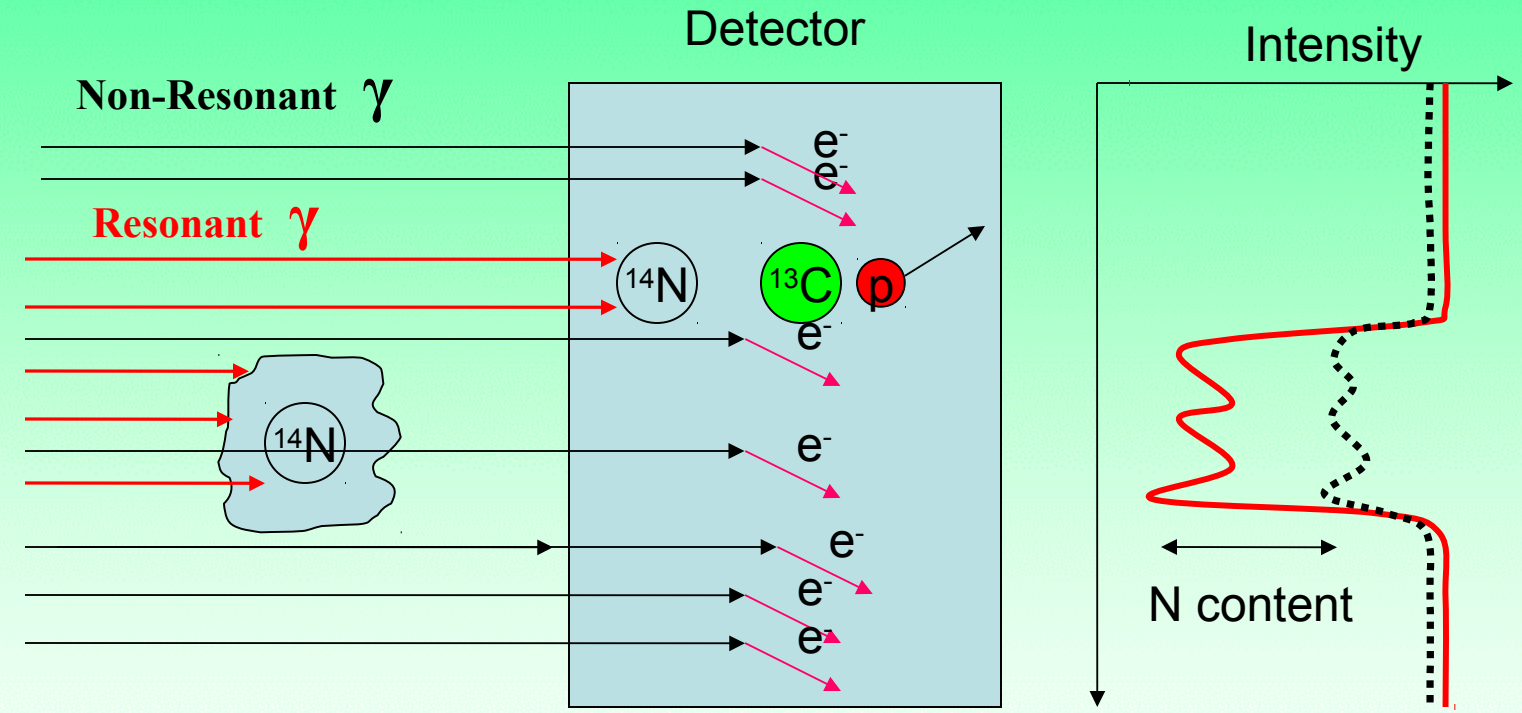


Fig. 1: Resonant absorption $\sigma_{ABS}(E)$ (square dots) and non-resonant (solid line) cross-sections for ^{14}N at 9.17 MeV

Gamma Nuclear Resonant Absorption method of Nitrogen detection

(Proposed by Soreq NRC* to US FAA in 1985)



* Sorec National Research Center, Yavne, 81800, Israel

TPC – good detector for GRNA radiography

High 3D spatial resolution (order of 1 mm or better)

Large active volume

High density

High Nitrogen content

TPC on liquid Noble gases (LAr, LXe)

LNitrogen ?

Possible problems:
not noble, diatomic molecular.

$\rho_{LAr} = 1.4\ g/cm^3$

$\rho_{LN} = 0.8\ g/cm^3$

Maybe mixture LAr + LN?

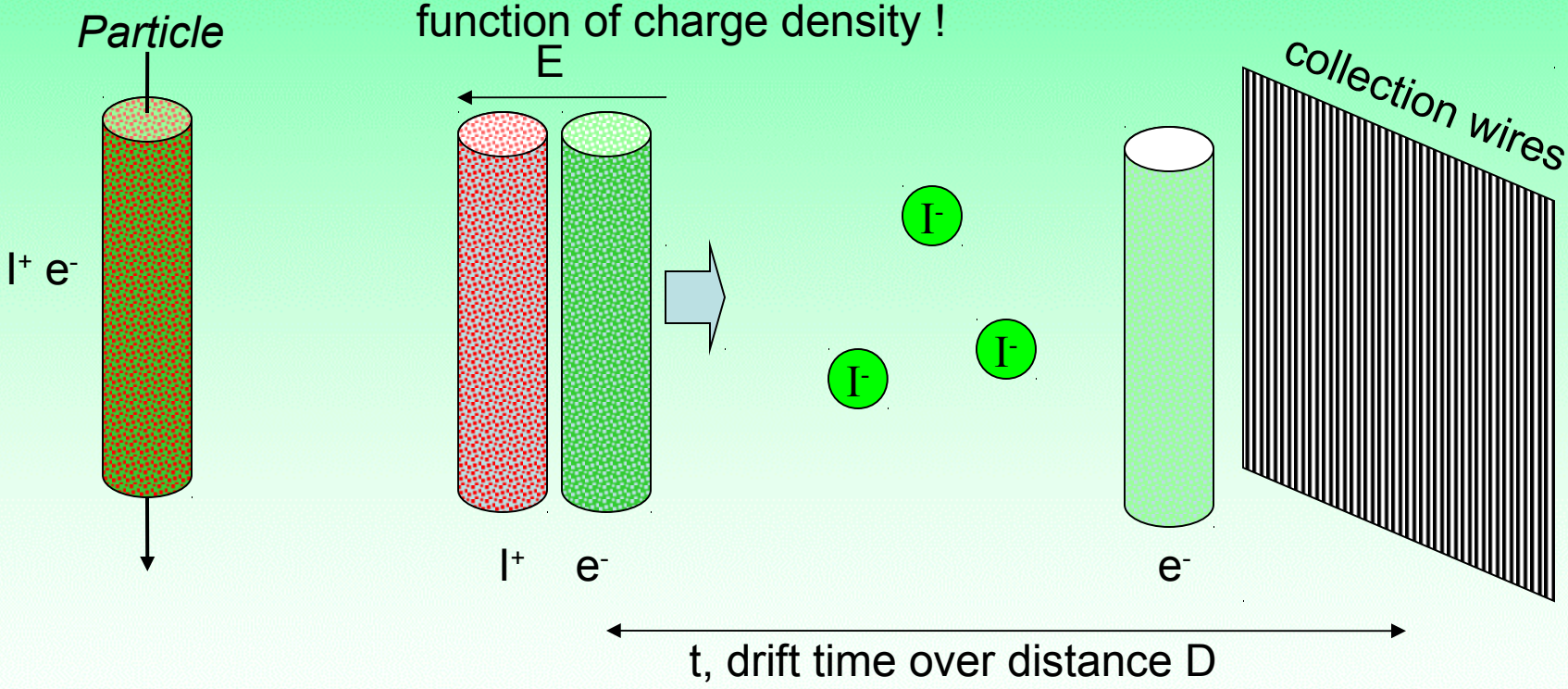
Concentration can be measured by measuring density – good.

Ionization charge in the TPC

Primary ionization
$Q_0 \sim dE/dX$

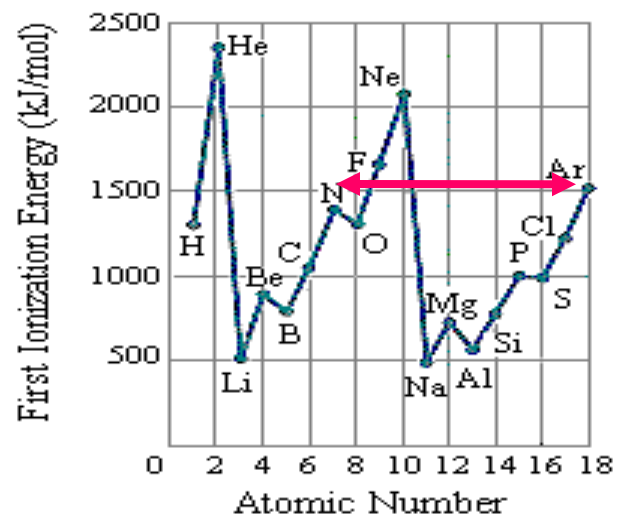
Recombination
losses $q_0 = A * Q_0$
Box model*:
function of charge density !

Attachment
losses $q = q_0 e^{-(t/\tau)}$



* J. Thomas and D. A. Imel, Phys. Rev. A36 (1987) 614-616.el

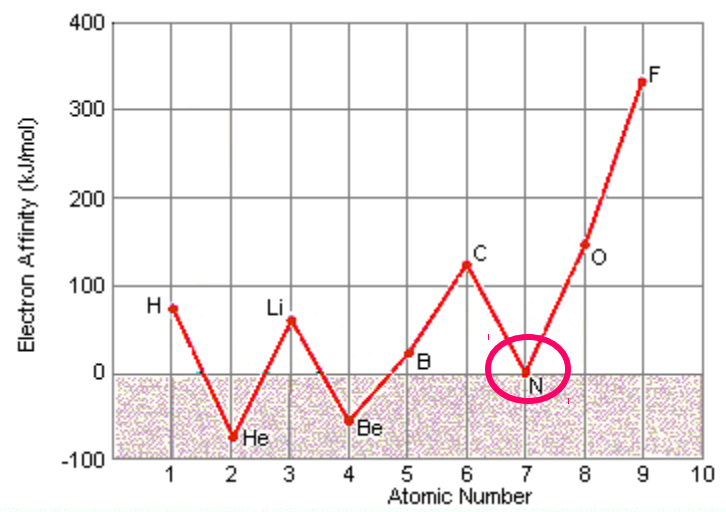
Ionization charge in Nitrogen



Ionization potential– same as Argon

Charge yield ?
- to be measured (electron thermalization)..

Recombination?
- to be measured



Attachment losses must be low,
In a thin chamber may be neglected?
- to be proven

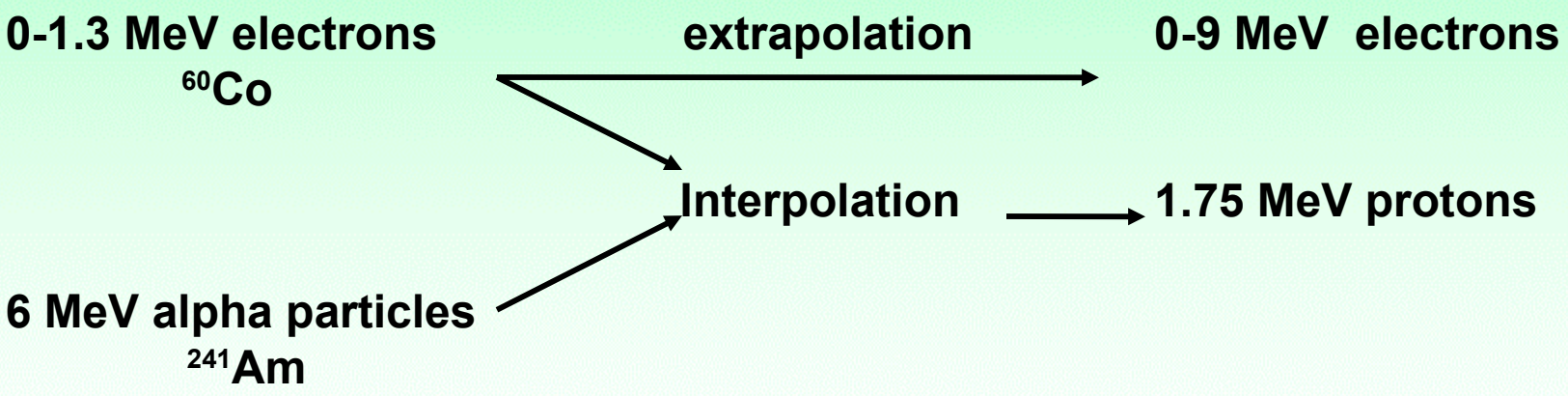
Must work at least up to certain Nitrogen concentrations ...

LArN TPC characterization

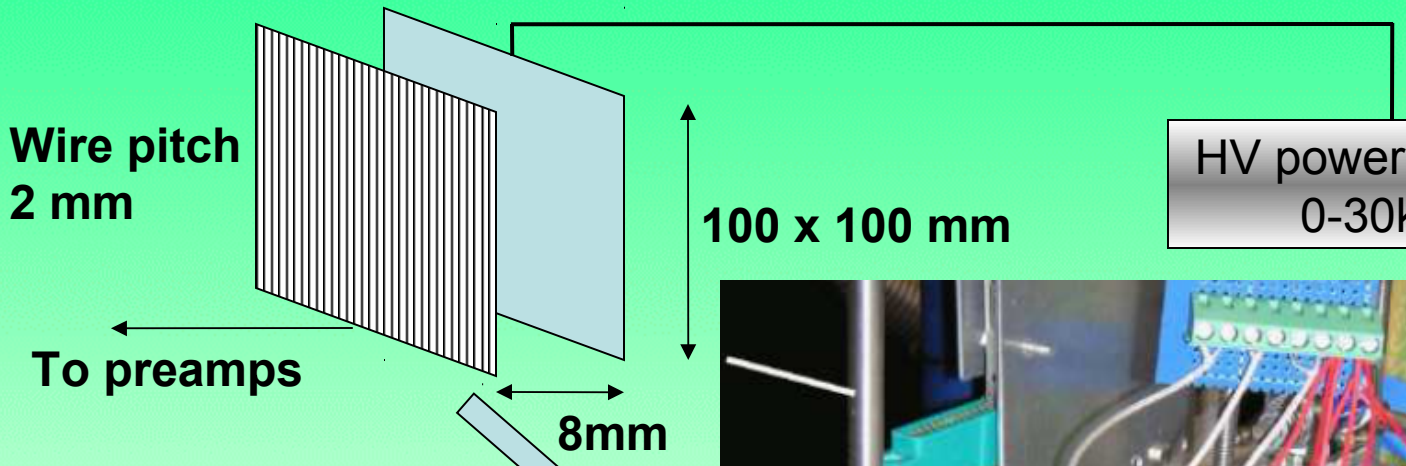
The goal: separation of 1.75 MeV protons from 0-9 MeV Compton electrons

Protons can't be delivered into TPC by any other methods, than GRNA

Solution:



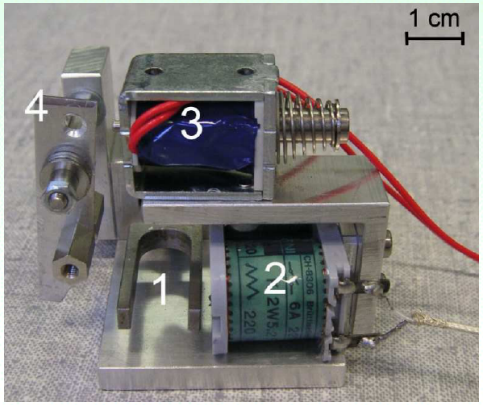
LArN TPC prototype

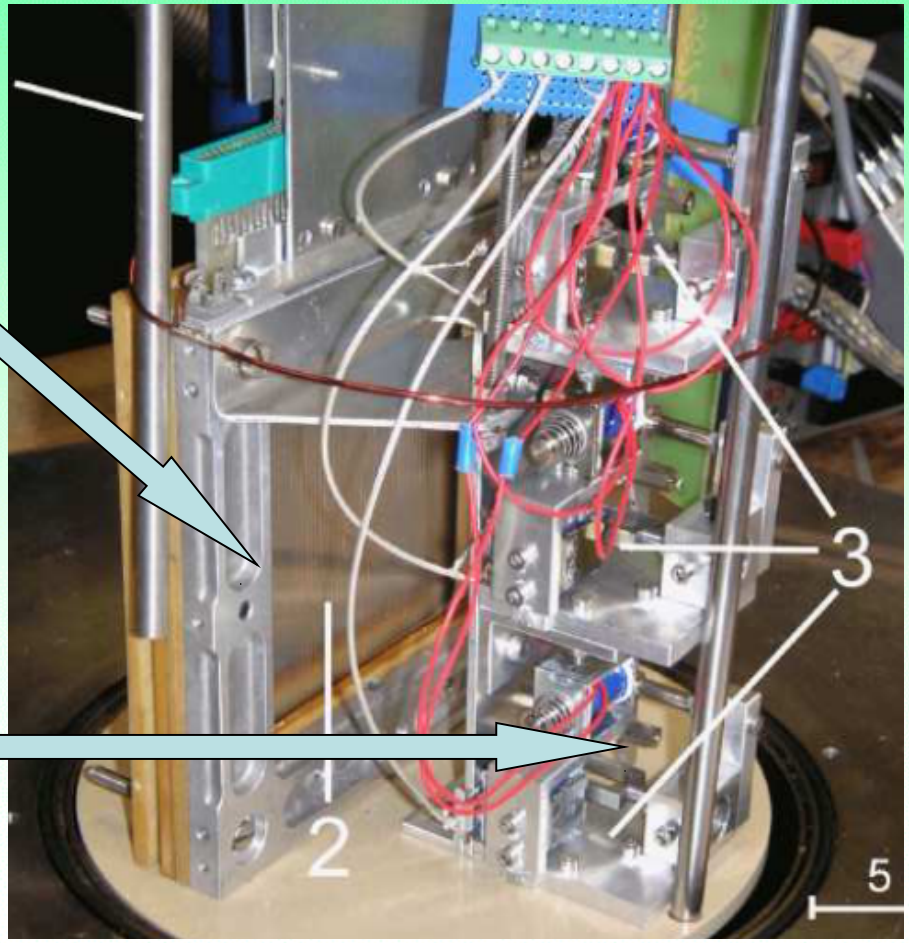


$\rho_{LAr} = 1.4\ g/cm^3$

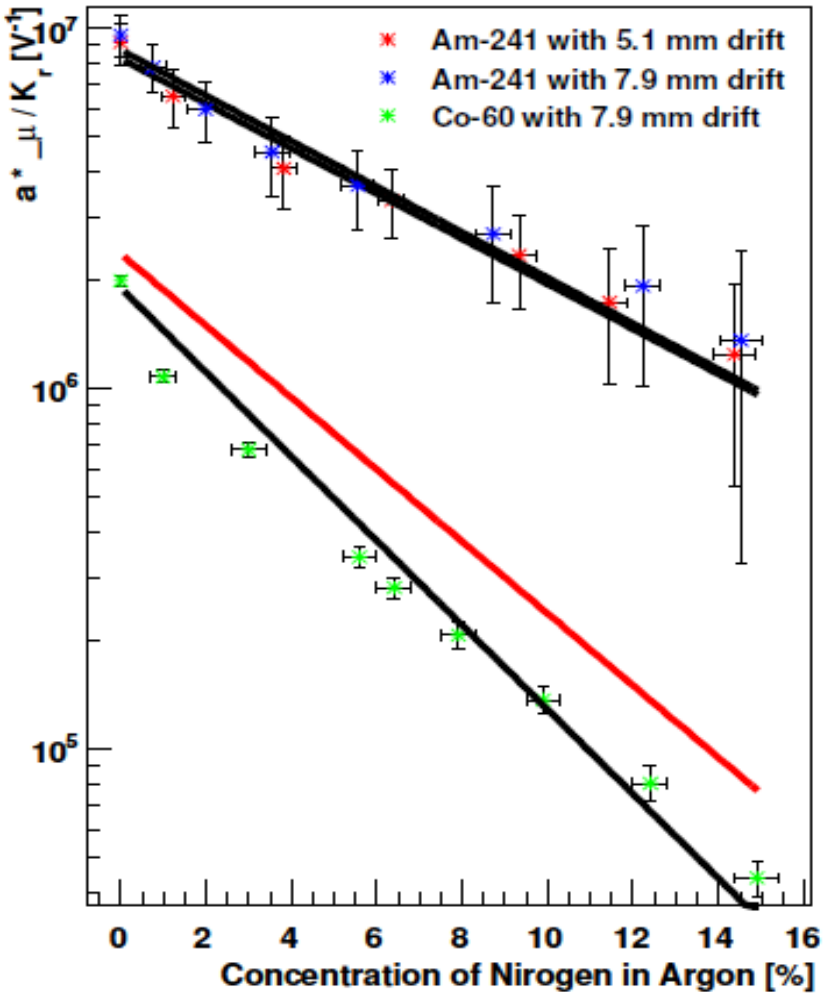
$\rho_{LN} = 0.8\ g/cm^3$

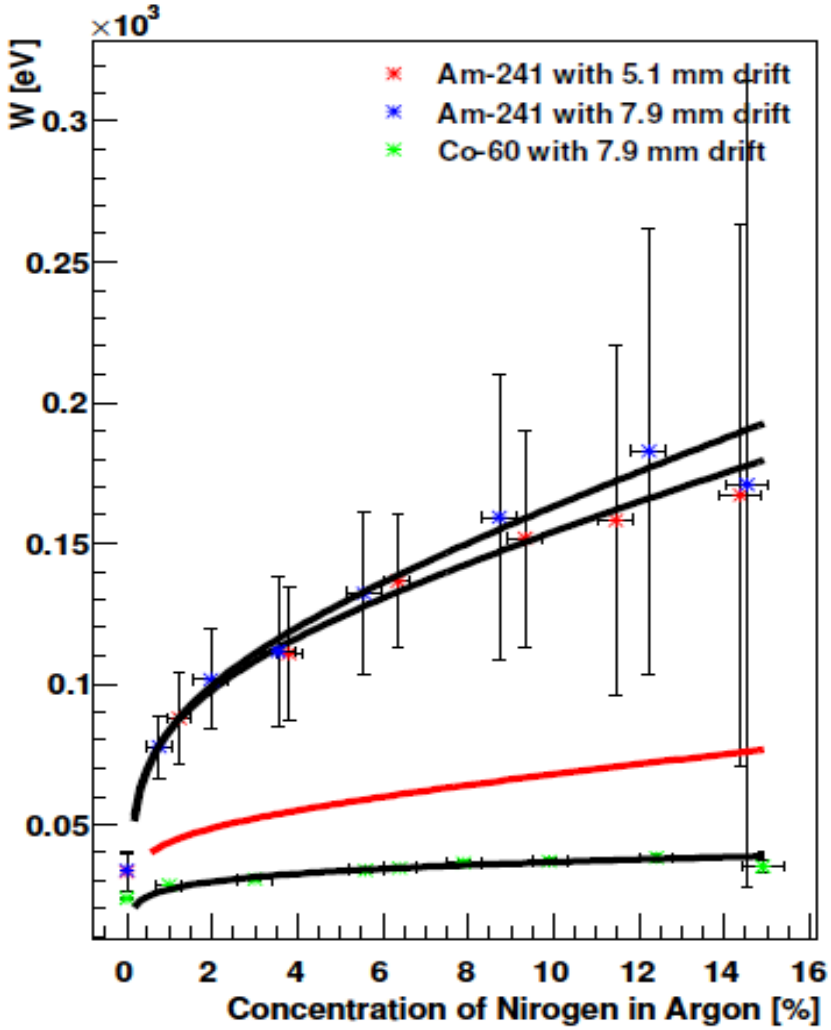
Concentration - density sensor:





Recombination and charge yield in LArN TPC





$$q_0 = \frac{E}{\kappa} ln\left(1 + \frac{Q_0 \kappa}{E}\right) \qquad \frac{au\_}{K_r} = \frac{1}{4eL\kappa},$$

Working parameters choice for GRNA

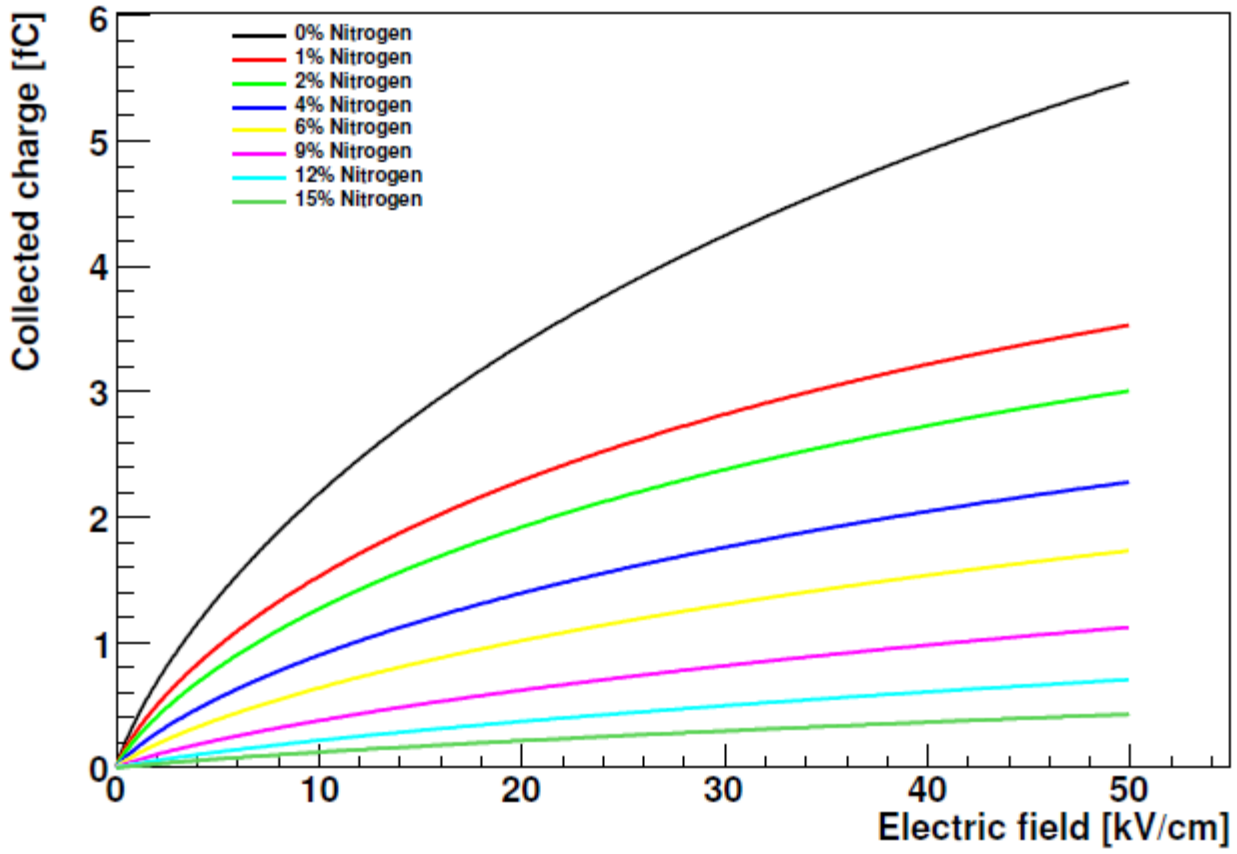
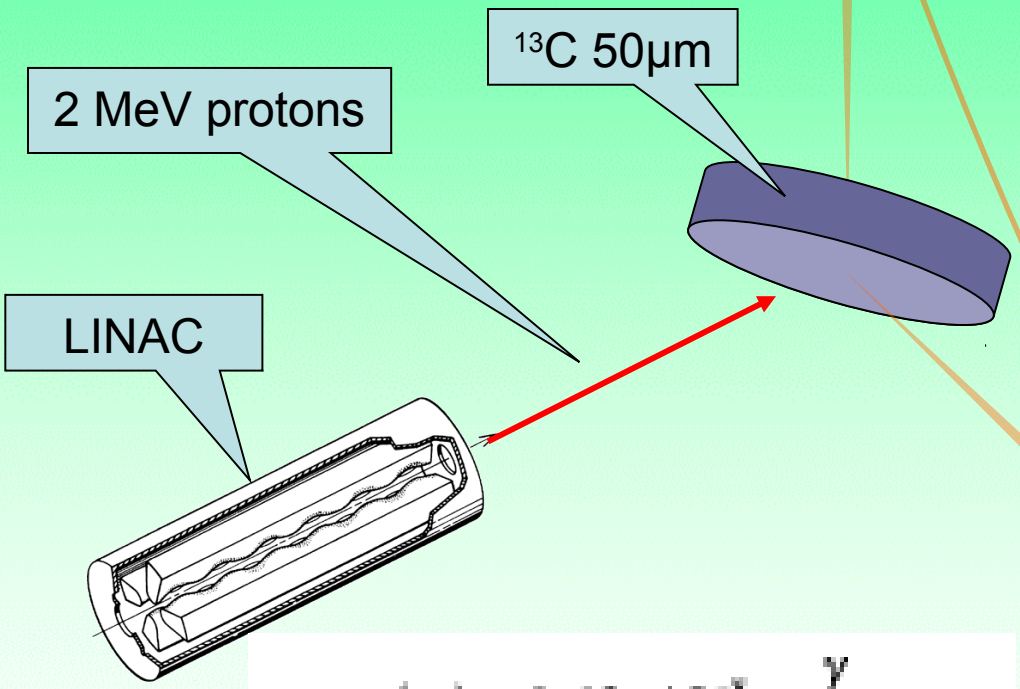


Figure 15. Expected ionization yield from protons of 1.75 MeV in a liquid $Ar - N_2$ TPC.

9.17 MeV Gamma source on the basis of the proton RFQ LINAC

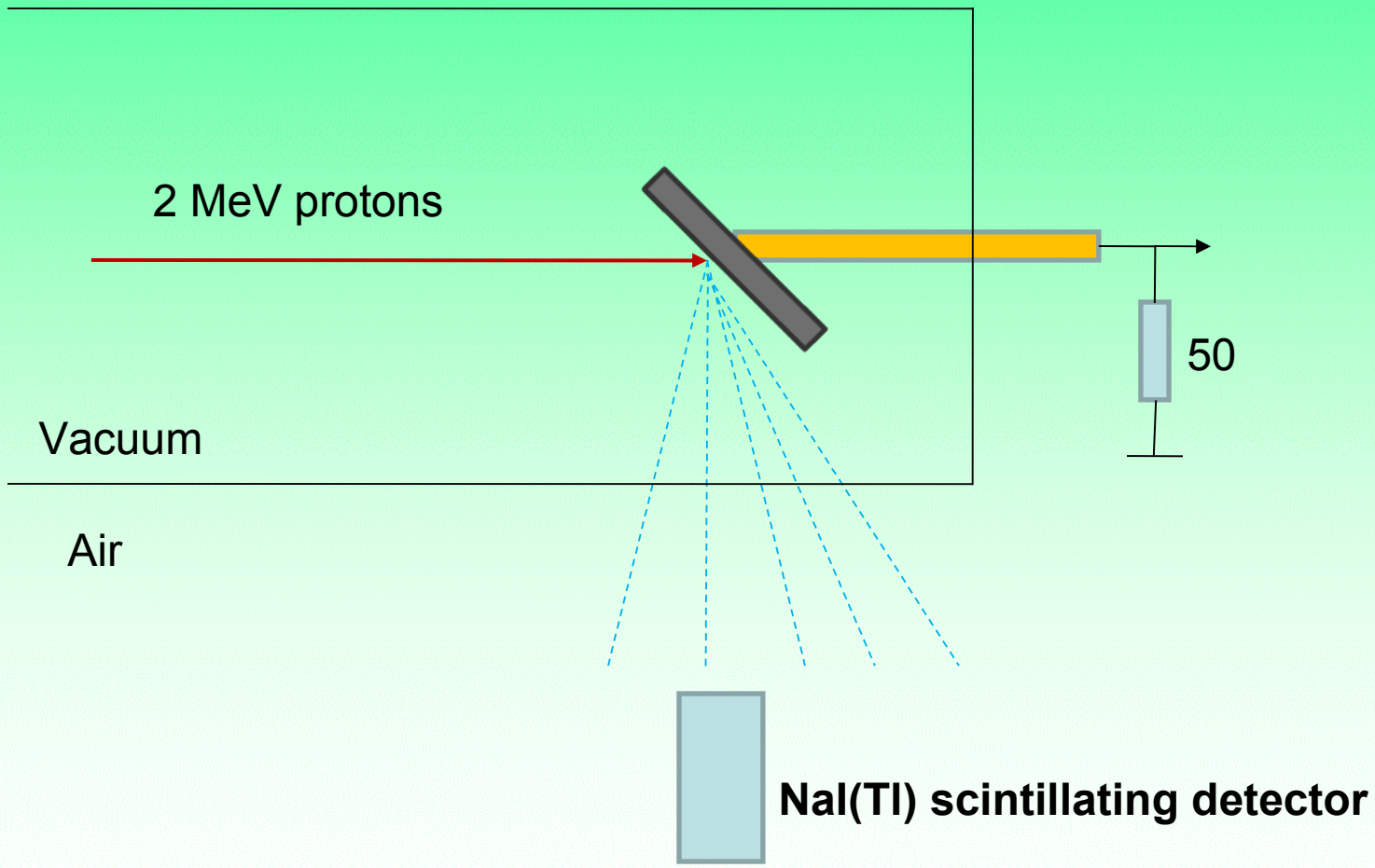
$$^{13}C+p \rightarrow {}^{14}N^{*} \rightarrow {}^{14}N+\gamma$$



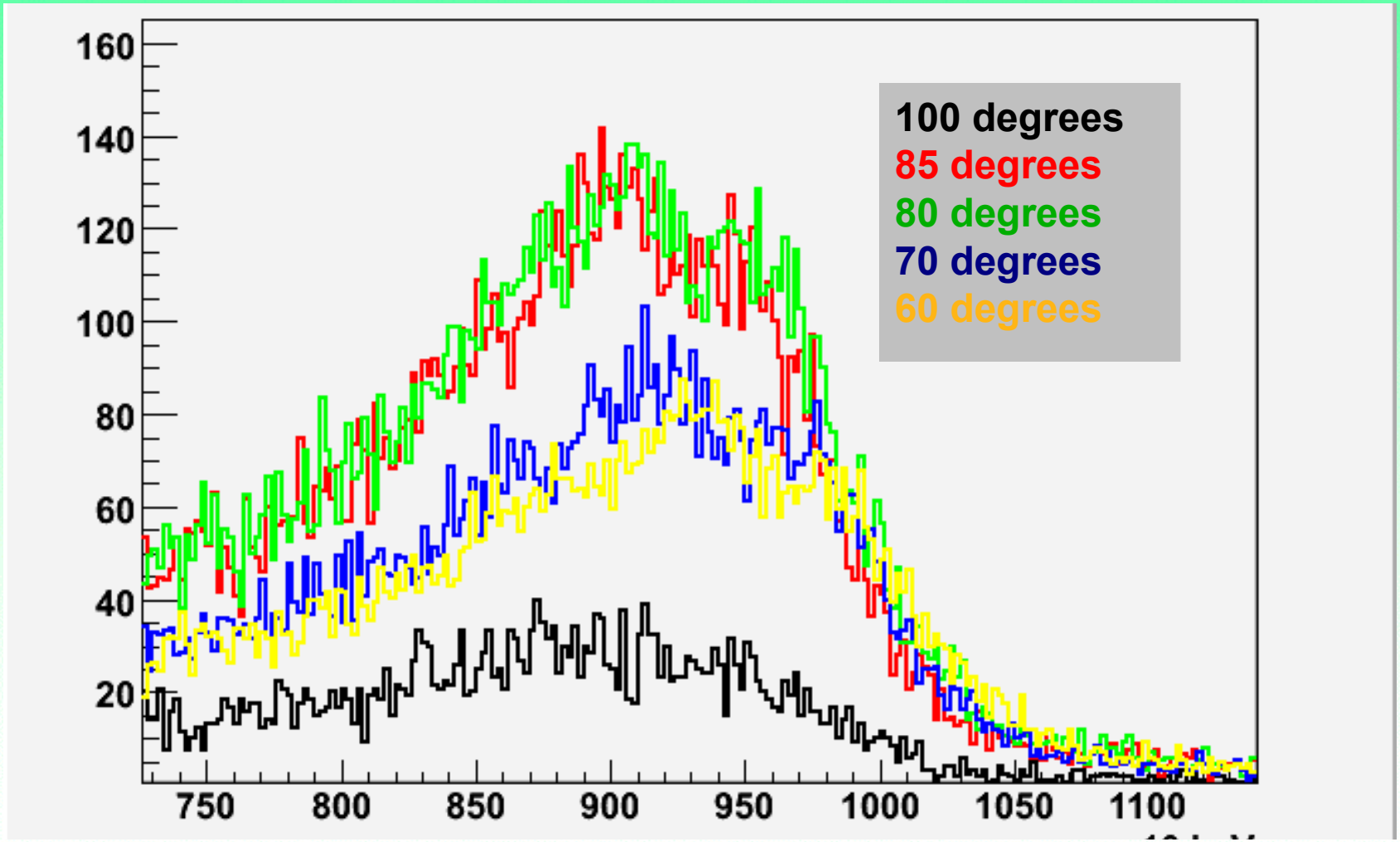
$$Y_{max}(\infty) = 0.63 \times 10^{-8} \frac{\gamma}{\text{proton}}.$$

9.17 MeV , **~130eV** FWHM
@~81 degrees

Tests of ^{13}C proton induced gamma emission



Tests of ^{13}C proton induced gamma emission: Energy spectra vs observation angle



To summarize:

A short drift gap Time Projection Chamber (TPC) filled with a mixture of liquid Argon and Nitrogen has been realized and successfully operated with Nitrogen concentrations of up to 15% for the first time.

Detailed studies on electron-ion recombination for different Ar -N2 mixtures with ^{60}Co-Compton electrons and alpha-particles from ^{241}Am were performed, results are published (JINST 3(2008): P10002; JINST 5 (2010) P10009)

The experimental results obtained for electrons and alpha-particles were combined to derive the expected ionization characteristics for 1.75 MeV protons. These results are essential to define the optimal working conditions for Gamma Resonant Nuclear Absorbtion (GRNA) radiography prototype.

The proton LINAC-based gamma source is commissioned

The GRNA screener prototype construction for feasibility study is ongoing.

Backup Slides

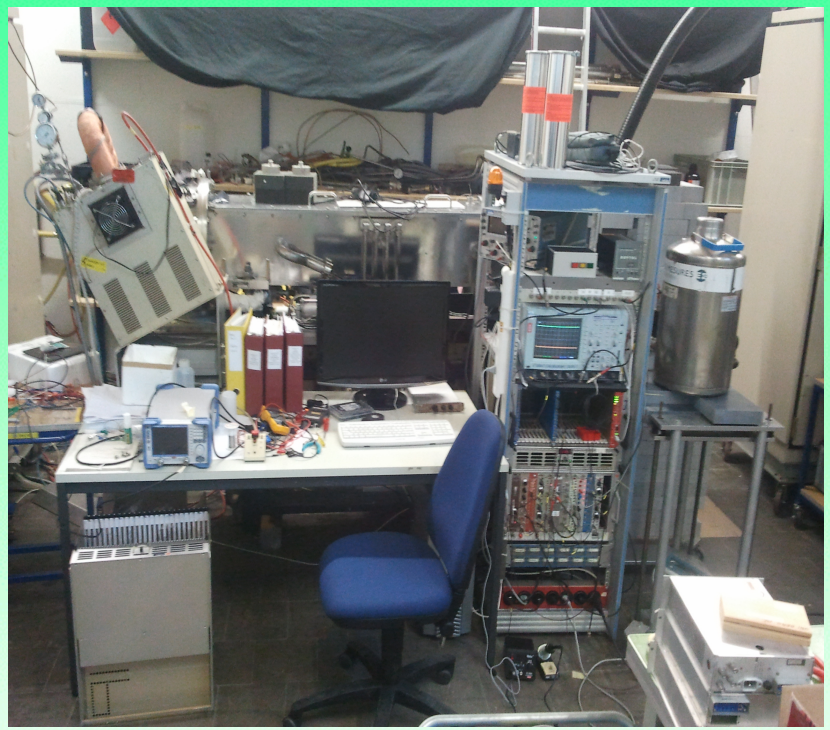
2 MeV proton RFQ for GRNA and other applications

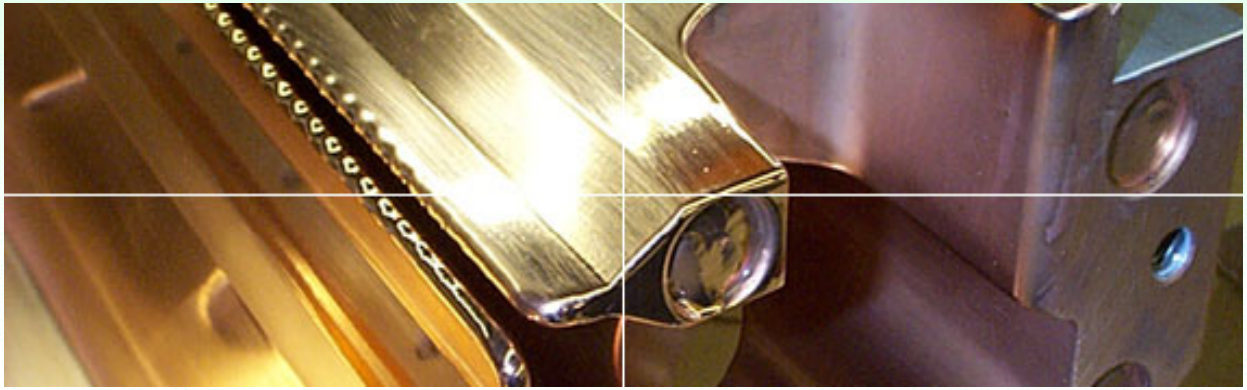
Commissioned at LHEP (Bern) in 2009

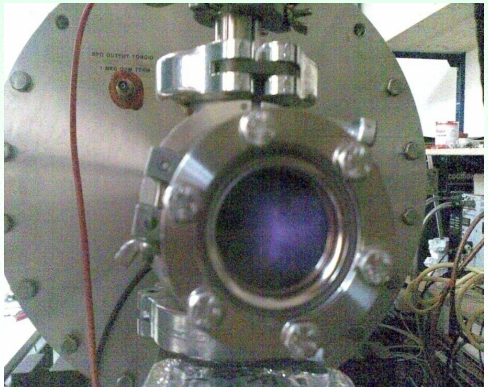
In 2011 stable pulsed H- beam:

Repetition rate 50 Hz
Pulse width 10 microsecond
Peak current 5 mA

Many thanks to CERN AD for help!







Carbon-13 target for LINAC-based gamma-source

Plasma-enhanced CVD from CH_4

Tantalum substrate 1mm thick

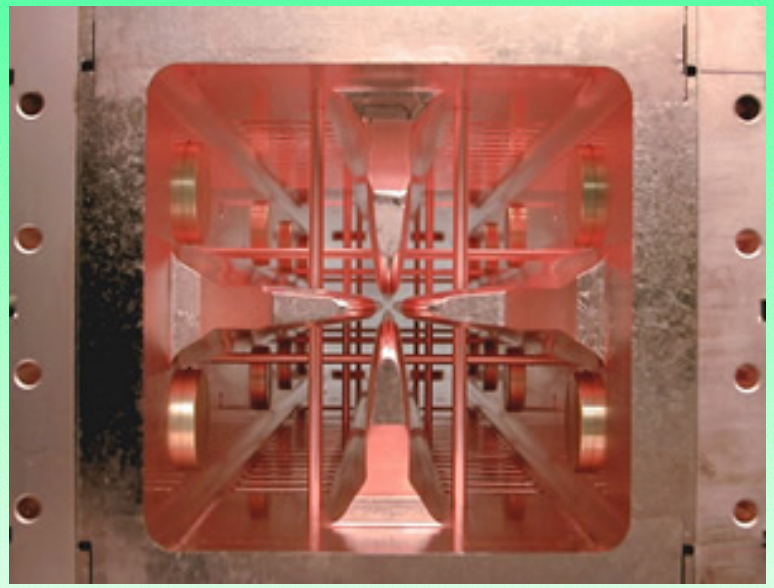
13C layer 15 microns thick

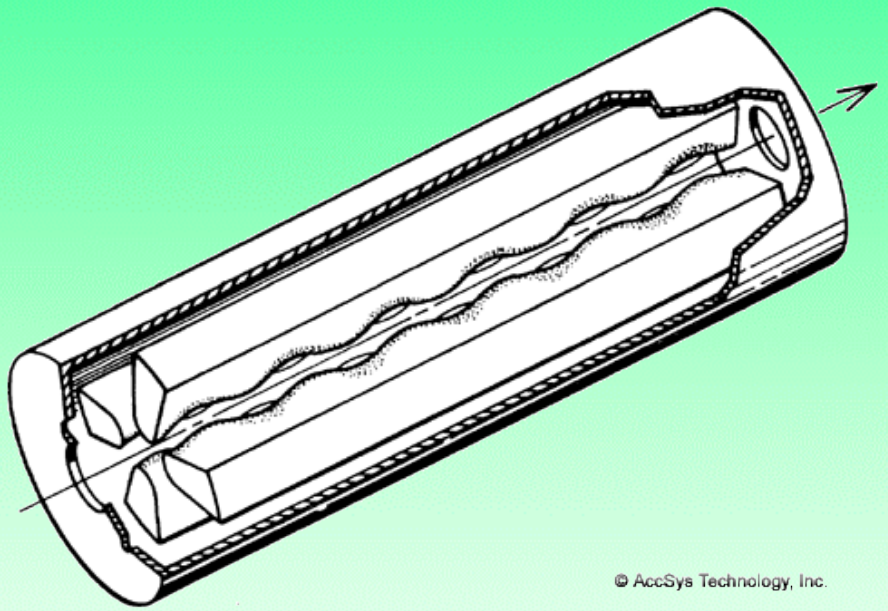
Diamond-like crystalline structure

Many thanks to CERN AD again!

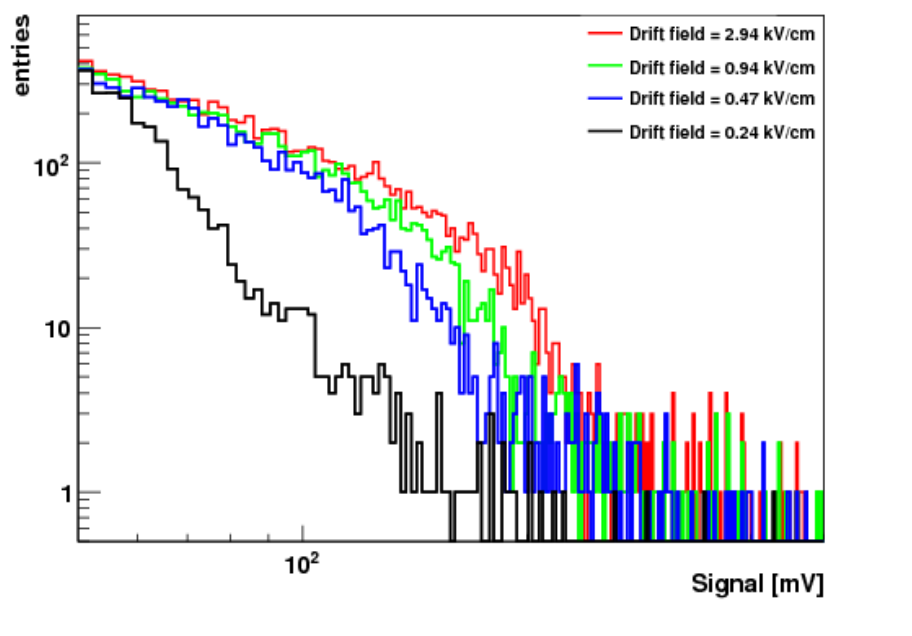
Radio Frequency Quadrupole LINAC

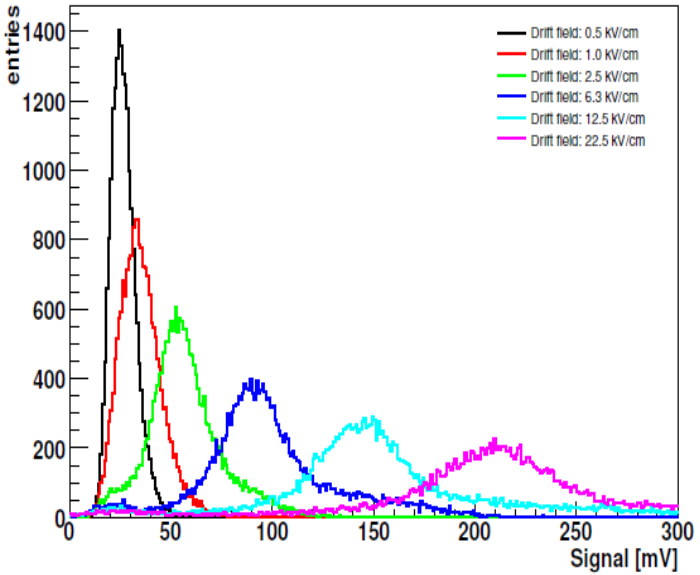
Invented in 1970 two Russian scientists, I.M. Kapchinski and V.A. Teplyakov





LArN TPC response to Compton electrons and alpha-particles





TPC response to alpha-particles at different Nitrogen concentration fitted with the “Box” model.

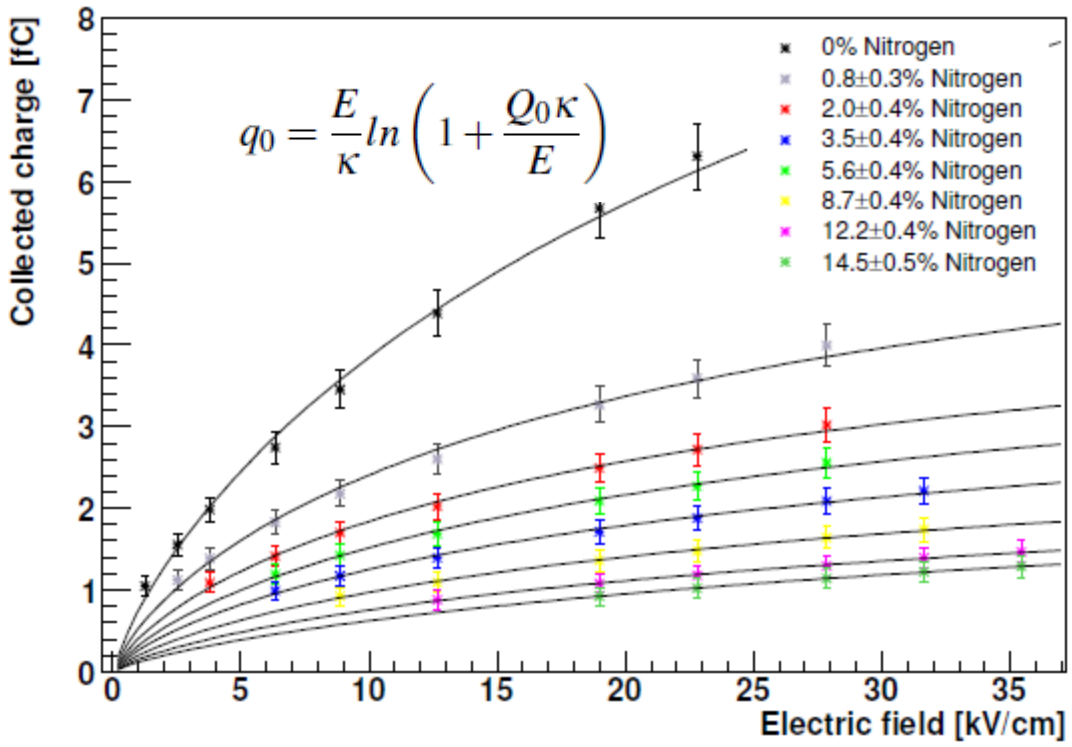


Figure 9. Collected charge produced by an ^{241}Am source for different drift-field intensities and Nitrogen concentrations. The ^{241}Am source is placed directly at the cathode plate of the TPC, so that the drift distance is 7.9 mm. The calibration procedure described in the text is applied. Points are fitted with the Box model.

Recombination: Box model

$$q_0 = \frac{4au\_eLE}{K_r} ln\left(1 + \frac{Q_0 K_r}{4au\_eLE}\right) \tag{2.4}$$

Introducing $\kappa = \frac{K_r}{4aeLu\_}$ we end up with the following expression:

$$q_0 = \frac{E}{\kappa} ln\left(1 + \frac{Q_0 \kappa}{E}\right) \tag{2.5}$$

$$\frac{au\_}{K_r} = \frac{1}{4eL\kappa}, \quad W = \frac{e * E_p}{Q_0}, \tag{2.8}$$

where W is the energy needed to create one electron-ion pair in the $Ar - N_2$ mixture and E_p is the energy of the ionizing particle, namely the mean energy for alpha-particles, and the Compton edge energy for electrons.

TPC energy resolution, derived from response to alpha-particles

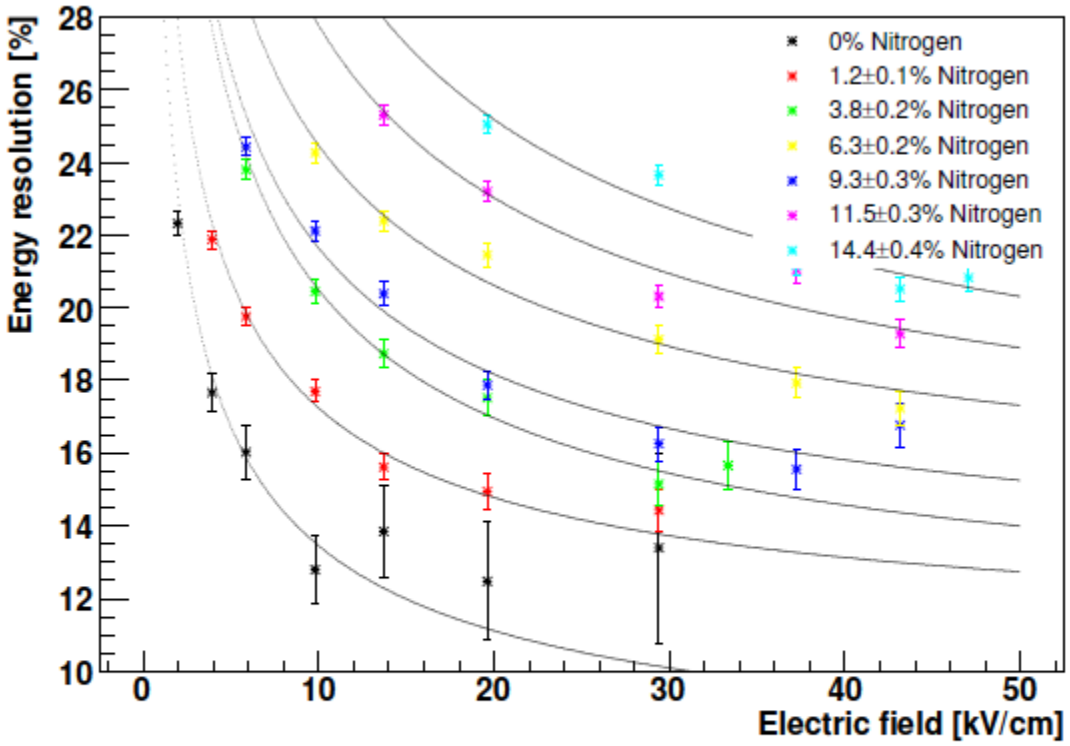


Figure 8. TPC energy resolution for different drift-field intensities and different Nitrogen concentrations. The drift distance is 5.1 mm. Data points are fitted with the $A + B/\sqrt{Q}$ function, where Q is the collected ionization charge.

TPC response to beta-particles at different drift fields.

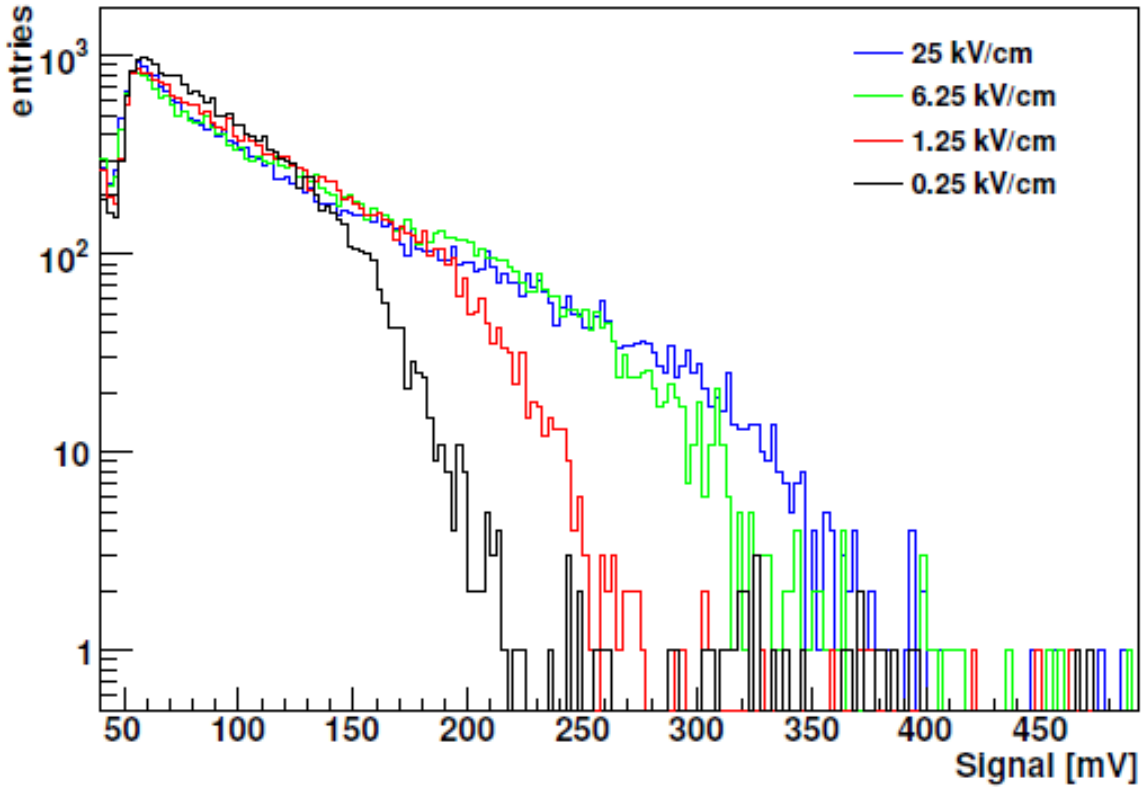


Figure 11. Measured spectra of the ionization charge from ^{60}Co Compton electrons for different drift fields. The TPC was filled with pure liquid Argon.

TPC response to beta-particles at different Nitrogen concentration fitted with the “Box” model.

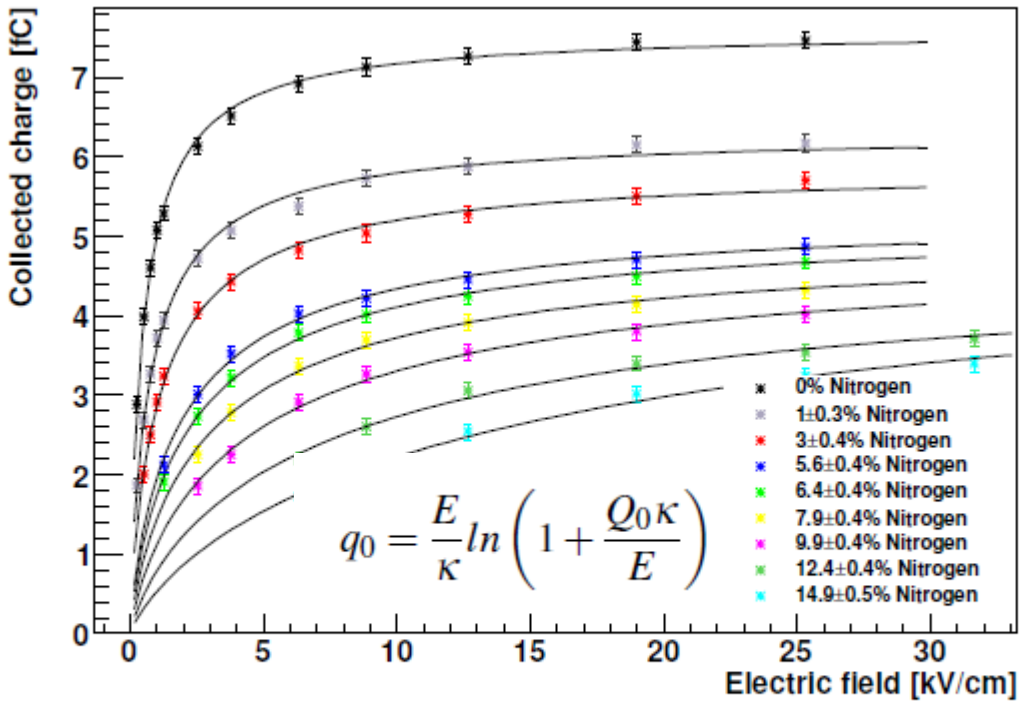


Figure 12. Collected charge corresponding to the Compton edge from ^{60}Co for different drift field intensities and different Nitrogen concentrations. Experimental data are fitted with the "Box model".