R&D with Bi207 source In LArTPC

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Outline

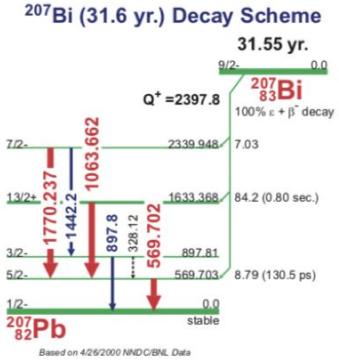
- R&D motivations
- Bi source and 50 liter LAR-TPC experimental set up
- Analysis
  - Muon tracks
  - Source data
- Present results
- MC validation

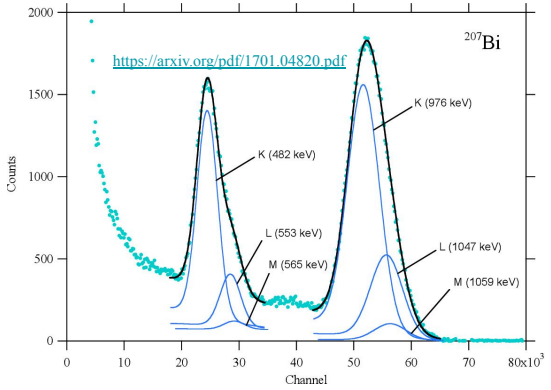
Using Bi207 as Calibration Source

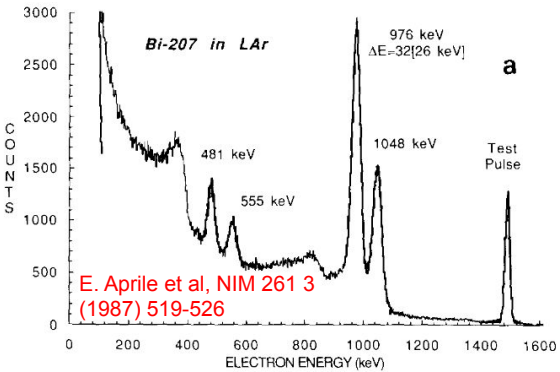
- Commonly used for calibration thanks to the intense monochromatic EC peaks

Decay Mode: EC, β^+		Half-Life: (11523 ± 1) d			[1]
Radiation Type		Energy (keV)		Intensity (%)	Ref.
Auger-L		5.2 - 15.7	53.8	14	[5]
Auger-K		56.0 - 88.0	2.8	3	[5]
ec-K-1		481.7	1.52	2	[5]
ec-L-1		553.8 - 557.7	0.440	6	[5]
ec-M-1		565.8 - 567.2	0.15	2	[5]
ec-K-2		809.8	0.003	1	[5]
ec-K-3		975.7	7.03	13	[5]
ec-L-3		1047 - 1051	1.84	5	[5]
ec-M-3		1059 - 1061	0.54	7	[5]
ec-K-4		1682	0.02	1	[5]
β+max		806.5	0.012	2	[5]
β+av		383.4			[5]
X-ray L	Σ	9.18 - 15.8	33.2	14	[5]
X-ray Kα	Σ	74.2	58.19	24	[5]
X-ray Kβ	Σ	84.4 - 87.6	16.22	25	[5]
γ		328.11	0.00076	8	[5]
γ	Annih	511.0	0.0024	4	[5]
γ		569.70	97.76	3	[5]
γ		897.8	0.131	6	[5]
γ		1063.7	74.58	49	[5]
γ		1442.2	0.131	2	[5]
γ		1770.2	6.87	3	[5]

Eckert & Ziegler
Contributing to saving lives





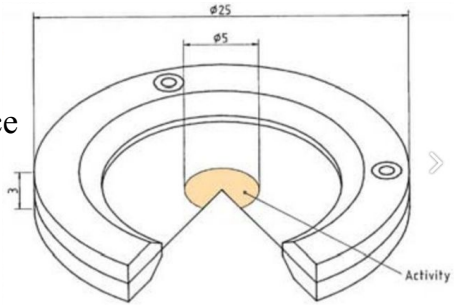


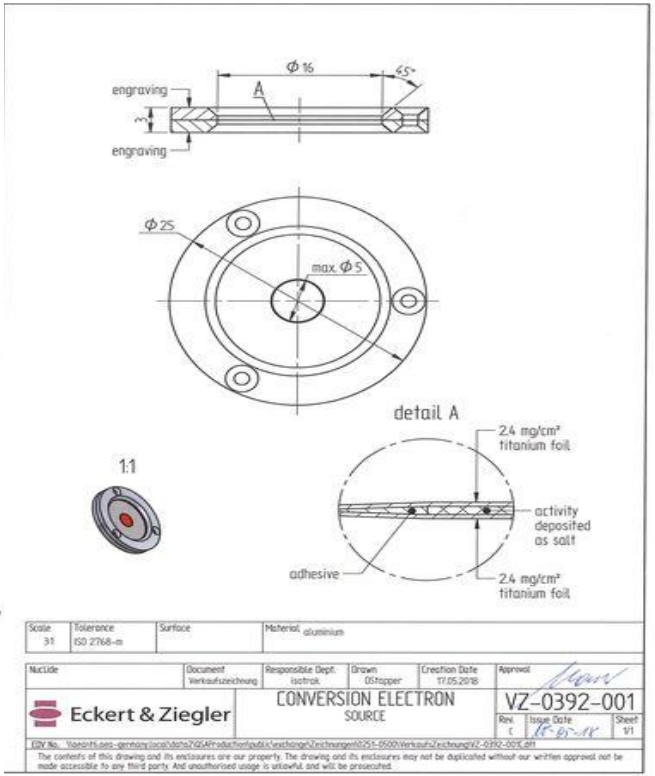
Pulse height spectrum of the Bismuth source in LAr, at E=10.9 kV/cm. The 976 keV electron peak is visible with a total energy resolution of 32 keV (fwhm). (*E . Aprile et al*)

Source recently acquired by CERN NP

- 3kBq from Eckert & Ziegler 207 Bi with materials compatible with cryogenic conditions (also available up to 37 kBq)
- Source protected by titanium or metalized mylar thin foils.
- Certified for cryogenic, vacuum and HV use.

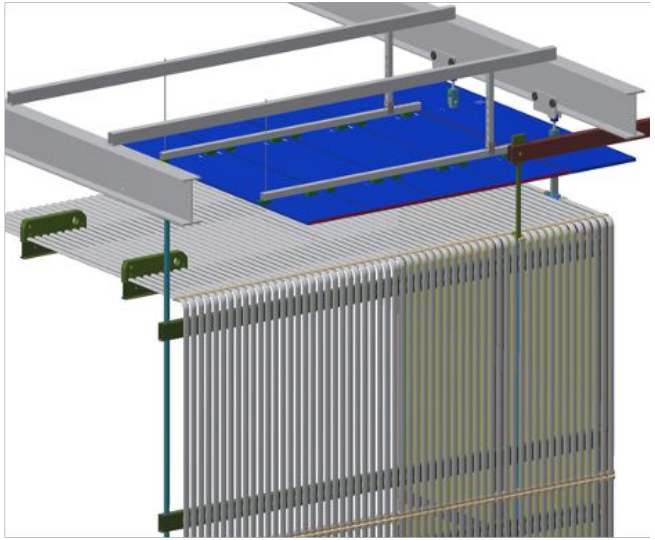
- Certification: ~ 5 kCHF
- Each source ~ 3 kCHF
  - Price should significantly reduce for bulk acquisitions





Bi207 sources in DUNE FD and ProtoDUNE ?

- 1 MeV monochromatic electron as an *additional tool* for continuous gain calibration, purity monitor and E-field uniformity in large LAr-TPC
- Possible close location in FD1 (insensitive to LAr purity) for electronic gain calibration of sample channels:
  - On the front face of the field cage I-beams, facing the APA at few cm distance (E-field to be verified)
- Far positions for integrated purity and E-field uniformity measure:
  - Matrix of sources on the cathode frame
  - Each facing different collection wires
- *Similar locations also possible for FD2*



Test plan at CERN

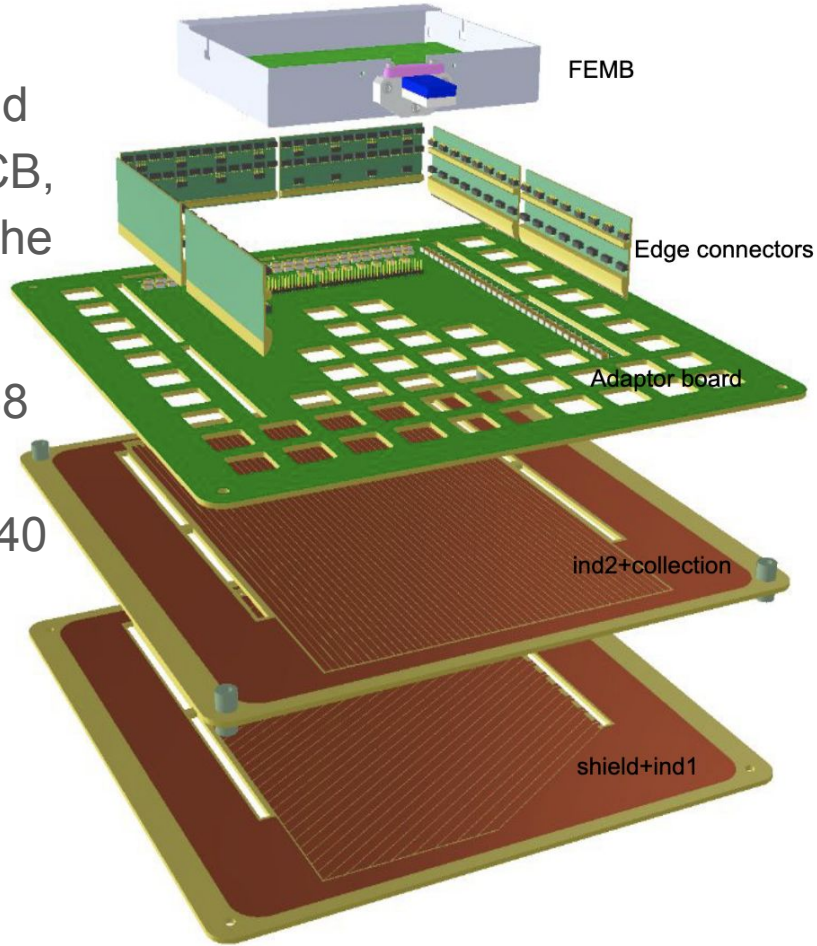
- Source integration in 50 Liter LAr-TPC during the perforated anode tests for Vertical Drift demonstration
  - Close location test (*April 2021*) with source at 1.5 cm from anode to demonstrate:
    - the ability to identify and reconstruct the 1 MeV IC peak above gamma Bgd
    - the achievable energy scale and resolution (comparing with mip particles energy deposition)
  - Far location tests (September/October 2021 and May 2022) with source on cathode (52 cm from anode) to demonstrate:
    - the ability to follow LAr purity evolution monitoring the charge collected from the 1 MeV IC peak, measure resolutions
- In this presentation we report on the May 2022 run only.

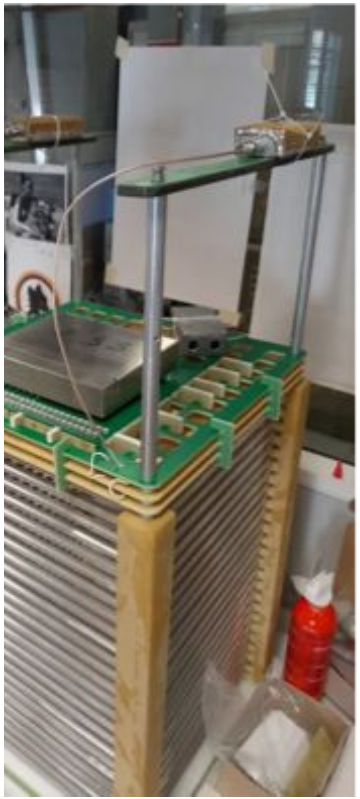
50L setup

3-view configuration with shield and induction-1 on the first PCB, induction-2 and collection on the second PCB

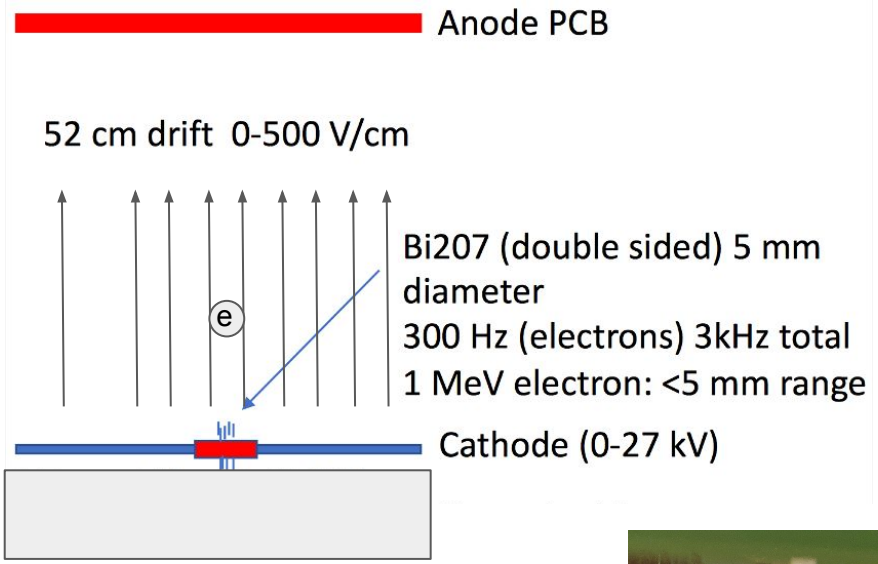
5 mm pitch collection strips (48 channels)
7.5mm pitch induction strips (40 channels each)

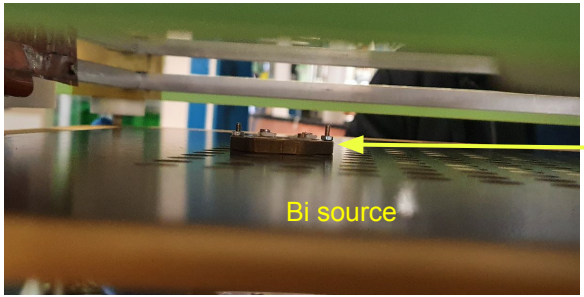
Partial active area to reduce number of channels and read them using a single DUNE/SBND FEMB

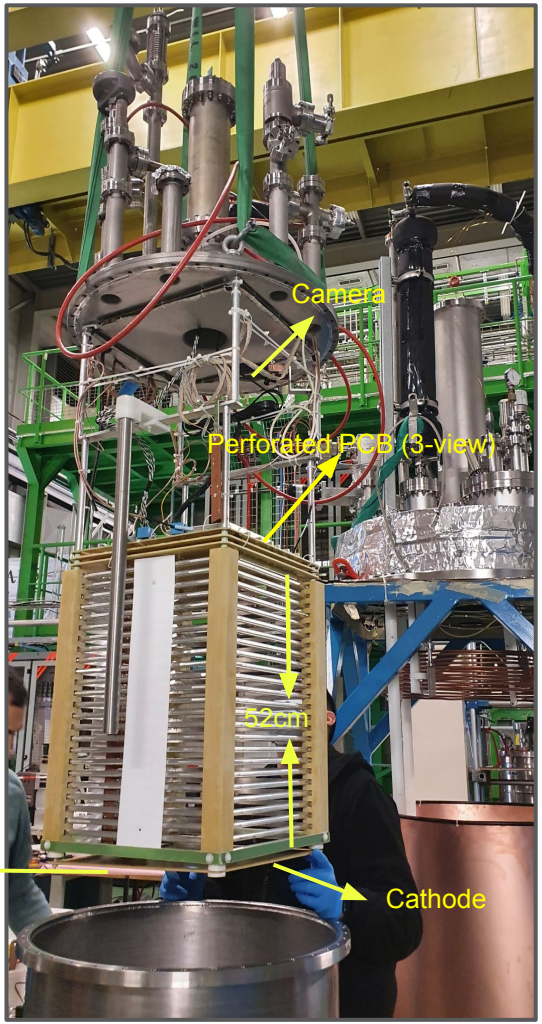




Bi207 in the 50L LAr-TPC







Triggers and DAQ

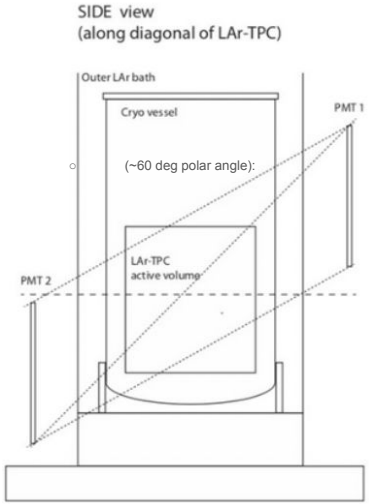
Run Duration: (40 days)
25 April - 4 June, 2022

DAQ:

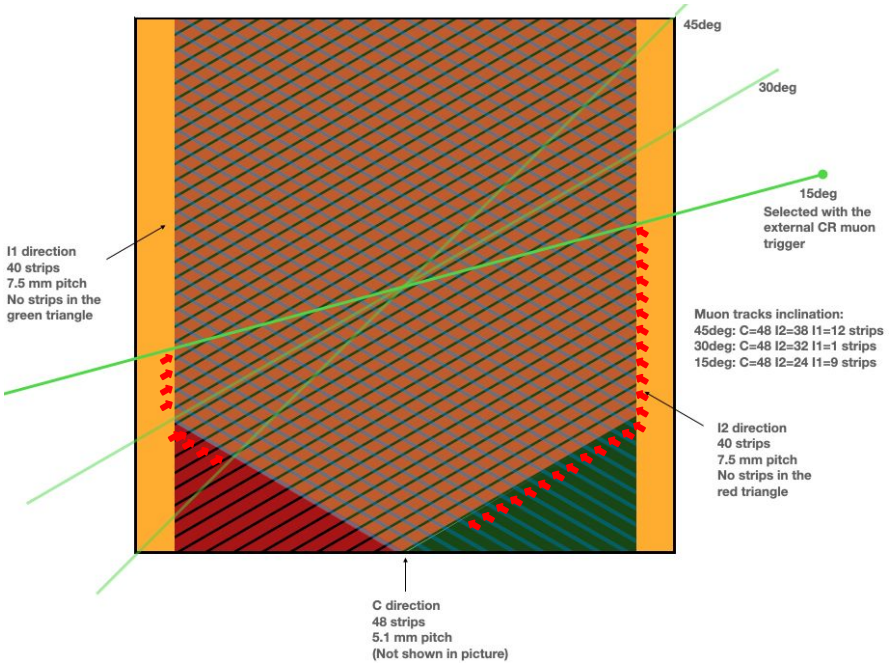
- Similar to ProtoDUNE-SP-I
  - WIB/FEMB Interface Software (from BNL)

Triggers:

- Random trigger (1-3 Hz)
  - Bi207 source
  - Electronic noise
- CR muons (~ 0.05 Hz)
  - External scintillators
- Charge Injection
  - channel gain calibration



Top view with anode strips and muon track orientation



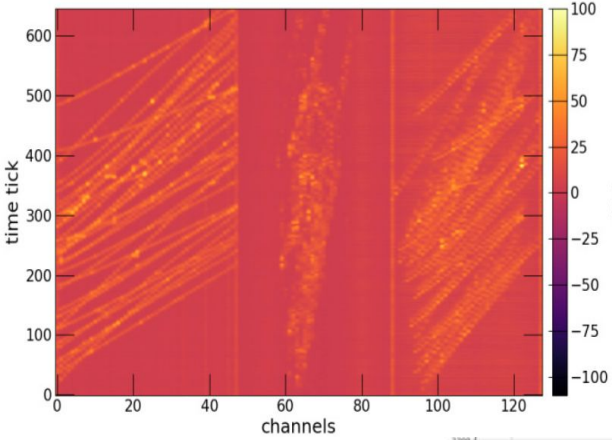
Analysis: 7 days (11-17May) of stable continuous operation

Good LAr purity (see later slide) and electronic noise conditions

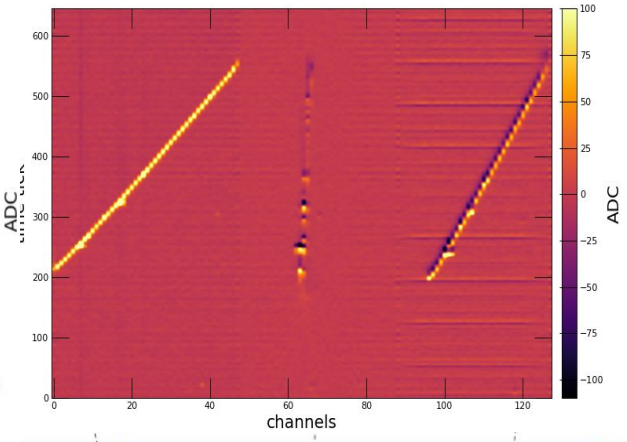
Filtered data from 250k collected triggers:

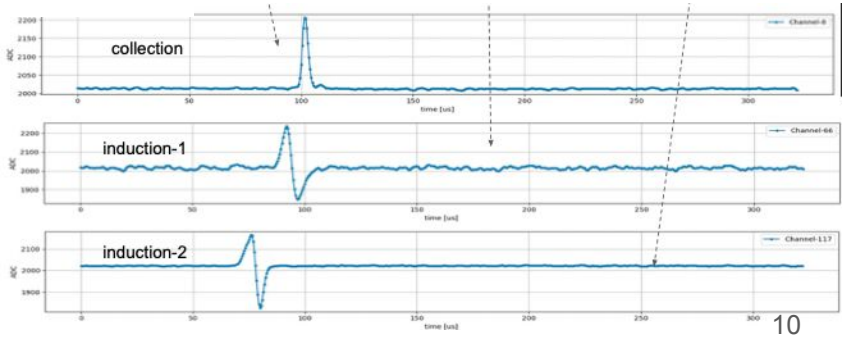
- ~ 7k Muon events used
  - one isolated tracks per event
  - without EM components
  - crossing all 48 collection strips
- Study Detector response
  - signal Characterization
  - space/energy resolution
  - electron attenuation length

Superposition of many muon tracks

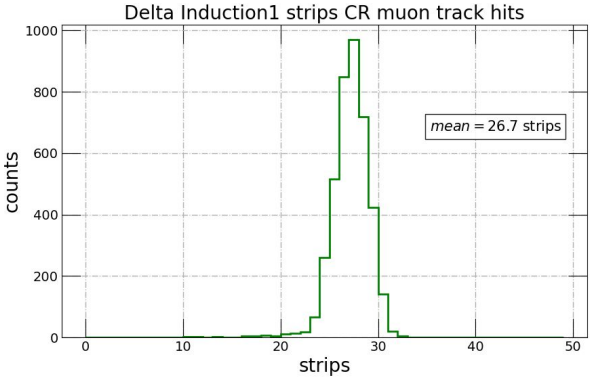


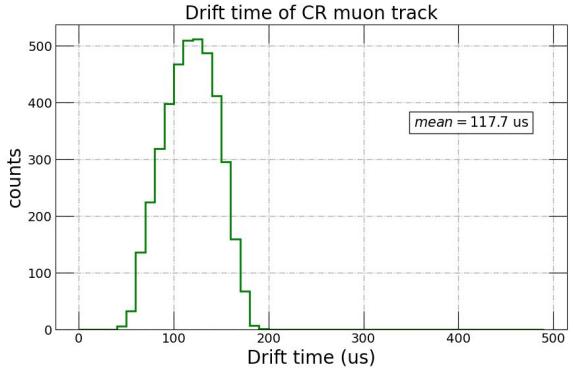
Single Muon Event

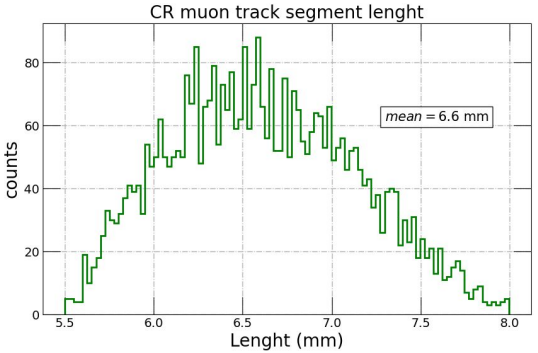




Cosmic muon tracks reconstruction





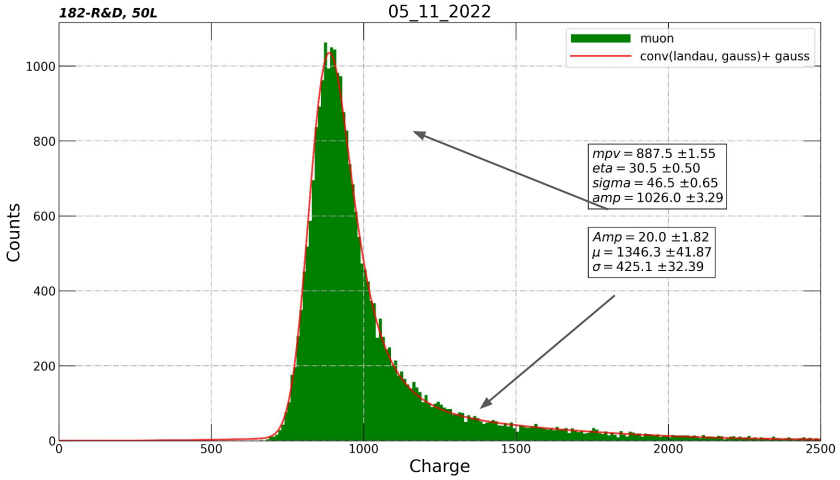


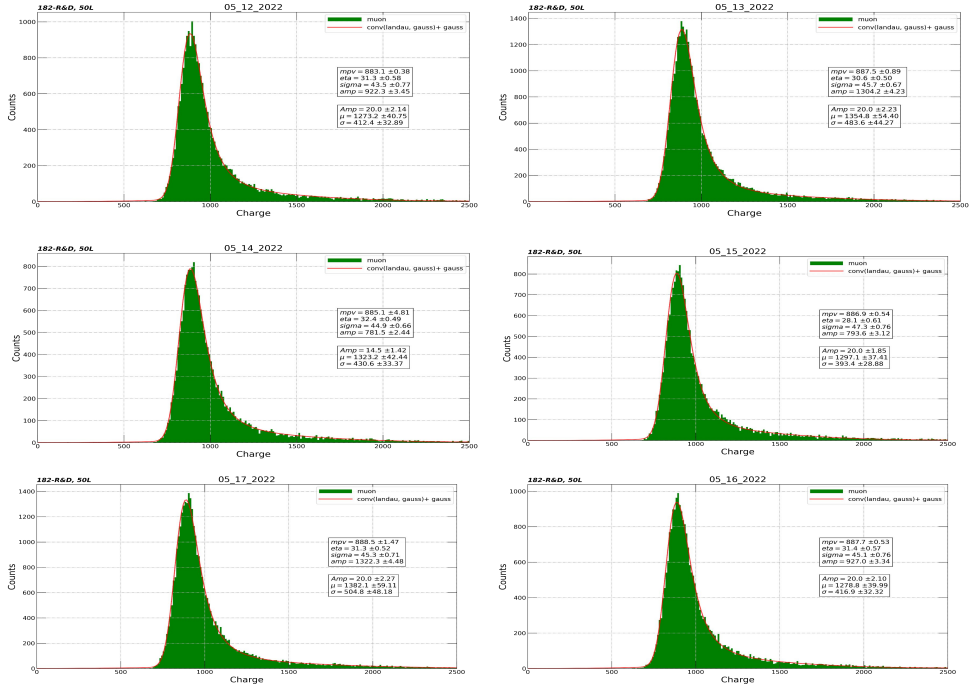
Average polar angle (from vertical direction) = 55°
Average plane angle (wrt collection direction)= 15°
To be included in MC to evaluate effective CR muon energy spectrum through the LAr-TPC

Effective track length on collection strip used to evaluate expected MPV of landau distribution

$$\Delta L = \sqrt{(\Delta T \cdot \frac{\delta t \cdot v_d}{\delta d})^2 + \frac{4}{3}\left[\Delta C^2 + \Delta I^2 - \Delta C \cdot \Delta I\right]}$$

Daily CR muon landau distributions (on collection strips, 6.6 mm effective pitch)





- Muon charge deposition on all collection strips (normalized for gain and track angle)

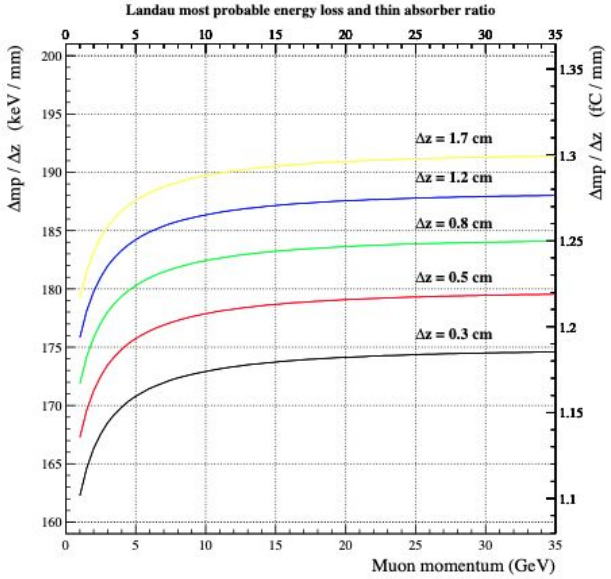
Fit with Conv(landau+gauss);

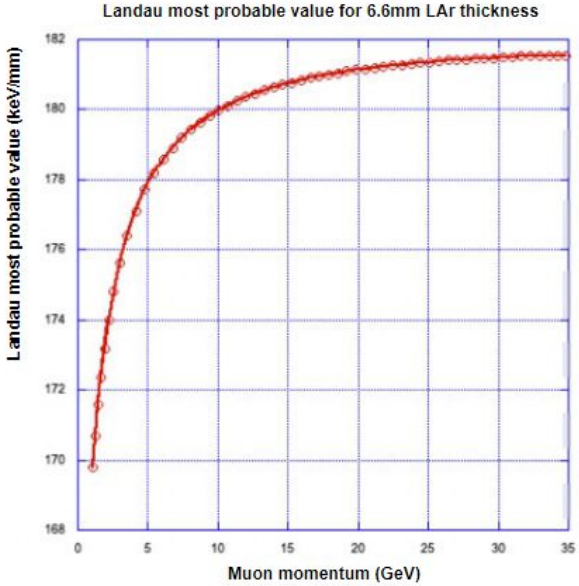
- 2nd gaussian added to fit, to account for deposition of energetic delta-rays produced on previous strip and continuing on next.

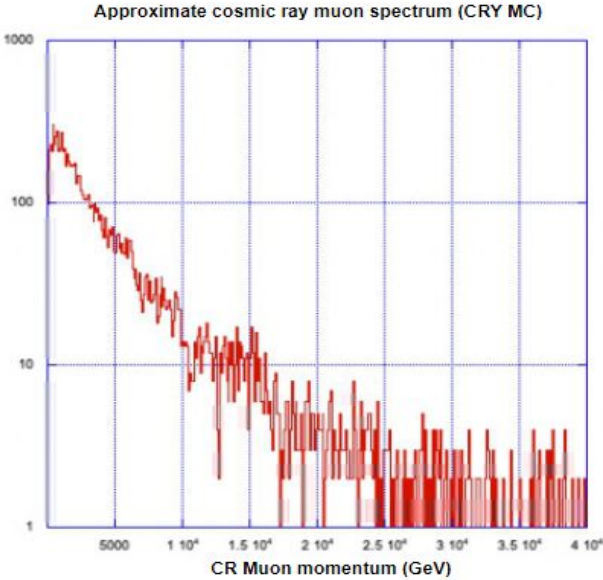
- Fit parameters compatible with expectation, signal/noise (on signal area) ~20

Very stable response over 7 days.

Evaluation of cosmic muon tracks energy deposition

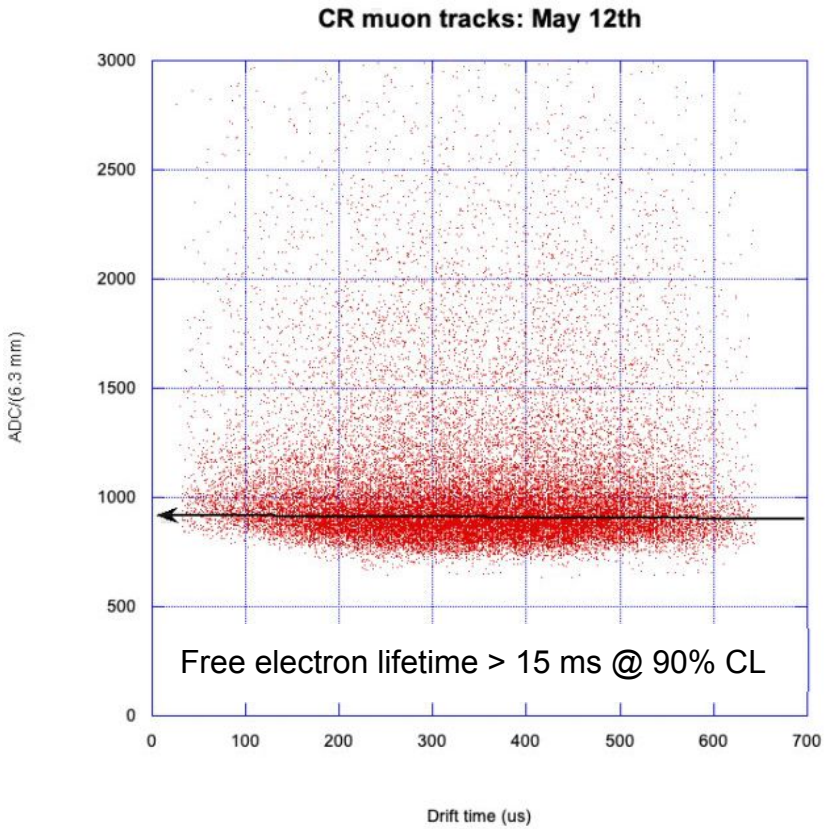






Approximate mean MPV averaged over CR muon momentum spectrum (CRY at 0 m ASL, all directions, 46° latitude): ~173 keV/mm
Uncertainty range: 170-182 keV
More accurate MC required to account for mu polar angle (~ 60 deg) and CERN elevation above sea level

LAr purity and charge deposition from CR muon tracks



All collected muons used to evaluate charge attenuation vs drift time

Charge on collection plane normalized track by track according to projected length on collection strips

Negligible charge attenuation along muon tracks observed for all data sets (11-17 May)

Source location and strips (3 views at 60 deg)

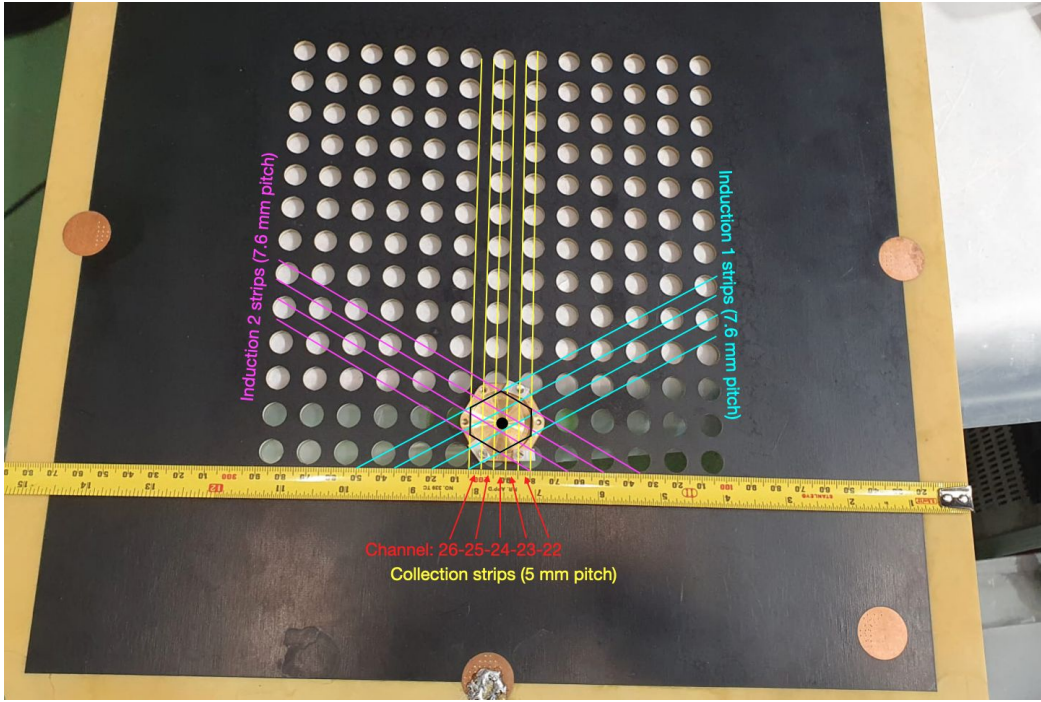
Source located on the cathode

Most energy deposited on a few channels

1 MeV electrons signals are expected to be shared maximum on 2 collection strips (5 mm pitch)

- Source diameter (5mm)
- Length of 1 MeV electron track (<5 mm)
- Most energy is deposited on collection strip 24 and 23.
- 5 collection strips (ch 22-26) considered for data selection (25 mm)
  - to evaluate gamma bkgd
- 3 induction strips considered (22.5 mm) in each induction views

These selection criteria largely suppress the compton electron bgd, given the ~12 cm gamma interaction length



Source data finding

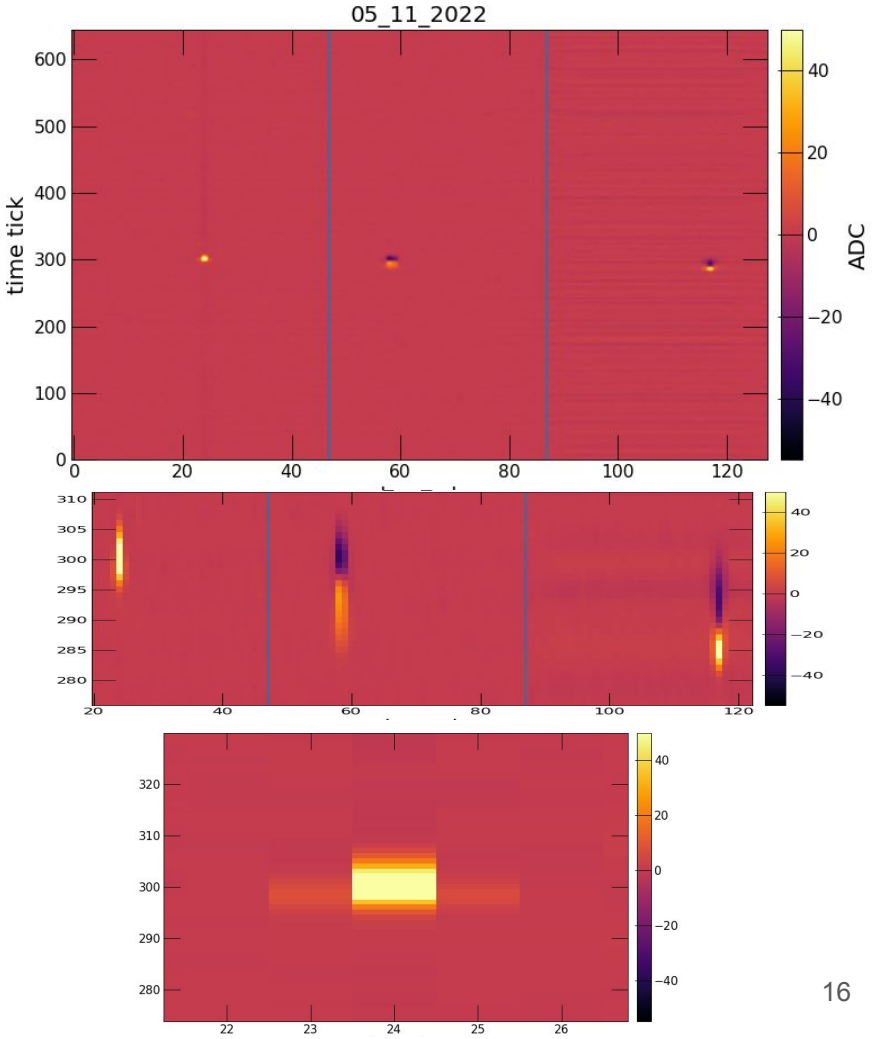
First filter out noisy events and events containing muon/em tracks from random triggered events (drift window = 320 us)

Source selection:

- Collection strips (22,23,24,25,26)
- Induction2 strips (57,58,59)
- Induction1 strips (116,117,118)

Charge measurement:

- sum of pulse area on the collection strip with signal above threshold and on the two adjacent strips



1 MeV EC selection efficiency

Very good LAr purity and electronic noise conditions

250000 triggers collected in 7 days

Expected random triggered events, containing one EC electron (@ ~ 1 MeV) candidates: 4.5%

- 3kHz (source activity) x
- 320 us (event buffer time depth) x
- 0.5 (one side of source only) x
- 10% (1 MeV EC peak relative intensity)

Actual events with source candidates (1 MeV EC + residual gamma background + lower energy EC electrons) after selection cuts:

- Removal of noisy evts: 91%
- Evts without muons tracks: 75%
- pulse height above threshold on all views: 9%
- 1 MeV EC candidates (after BG subtraction) ~ *2.25%*

*Overall 1 MeV EC detection efficiently ~ 2.25/(4.5*0.75)~ 66%*

total= 1416.0	RMS_veto= 1296.0	track_veto= 1062.0	ind1= 151.0	ind2= 149.0	col= 127.0
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total= 1440.0	RMS_veto= 1338.0	track_veto= 1080.0	ind1= 156.0	ind2= 156.0	col= 152.0
total= 1440.0	RMS_veto= 1336.0	track_veto= 1052.0	ind1= 147.0	ind2= 147.0	col= 149.0
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total= 1440.0	RMS_veto= 1330.0	track_veto= 1081.0	ind1= 137.0	ind2= 137.0	col= 124.0

Gamma BGD evaluation

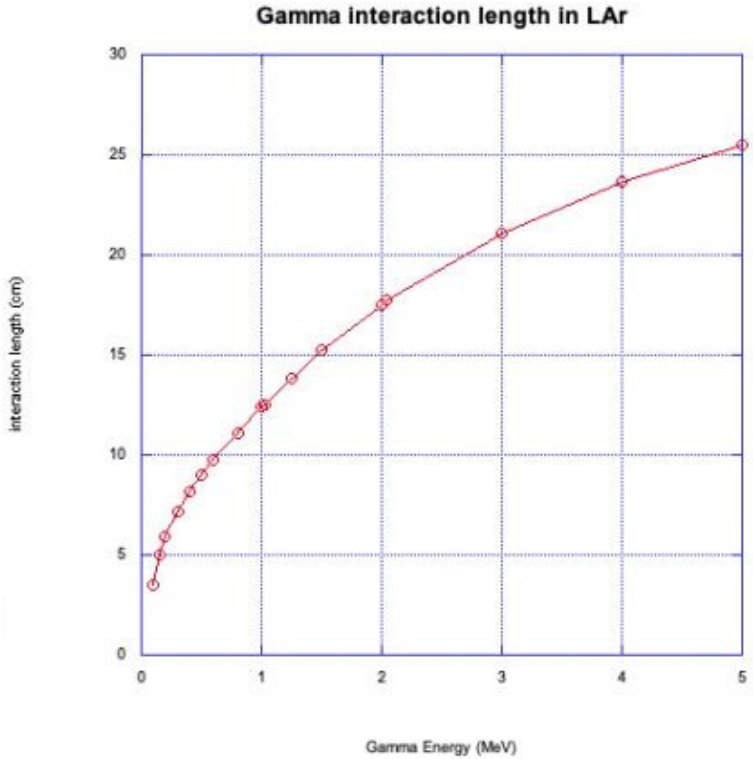
In the 0.5 - 1.1 MeV energy range the gamma bgd is largely due to the 1063.7 gamma (74.58% intensity), mainly producing compton electrons with ~12 cm interaction length.

Its compton electron spectrum has ~0.85 MeV end-point; the electron tracks (<4mm) are confined on single strips.

Because bgd is single gamma dominated, the spectra collected on adjacent collection strips are all similar in shape (only the intensity changes due to solid angle interception).

EC peak instead is localized on strip 24(23) because electrons range out immediately as they exit the source.

This feature can be exploited to evaluated the gamma bdg on the strips 24 (23) and subtract it from the 1 MeV EC peak.



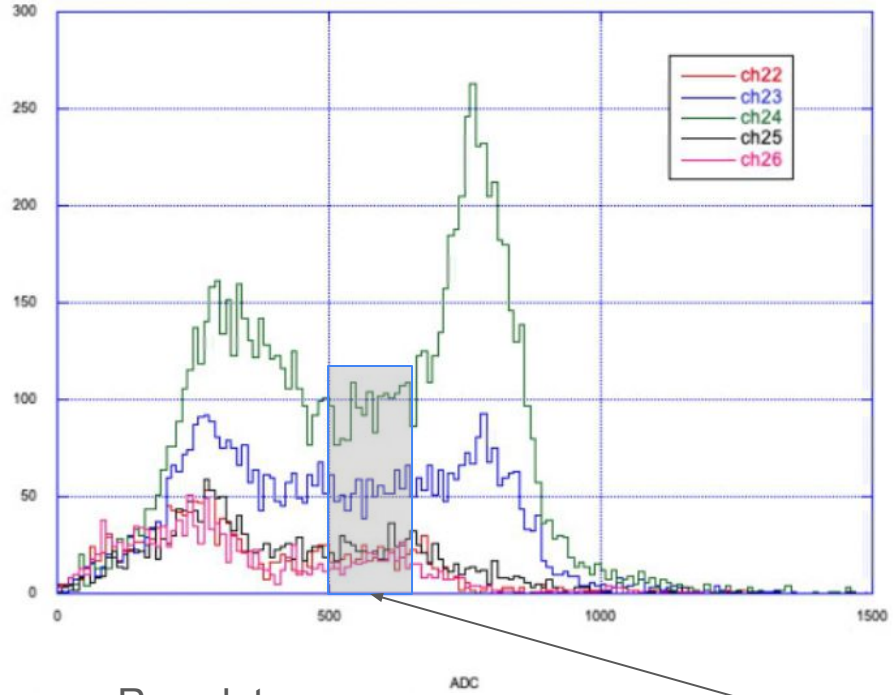
Source spectra (7 days)

Fit with double gaussian with fixed ratios of means (976/1050) and intensities (7.5/2.5); same sigma (mainly from electronics noise)

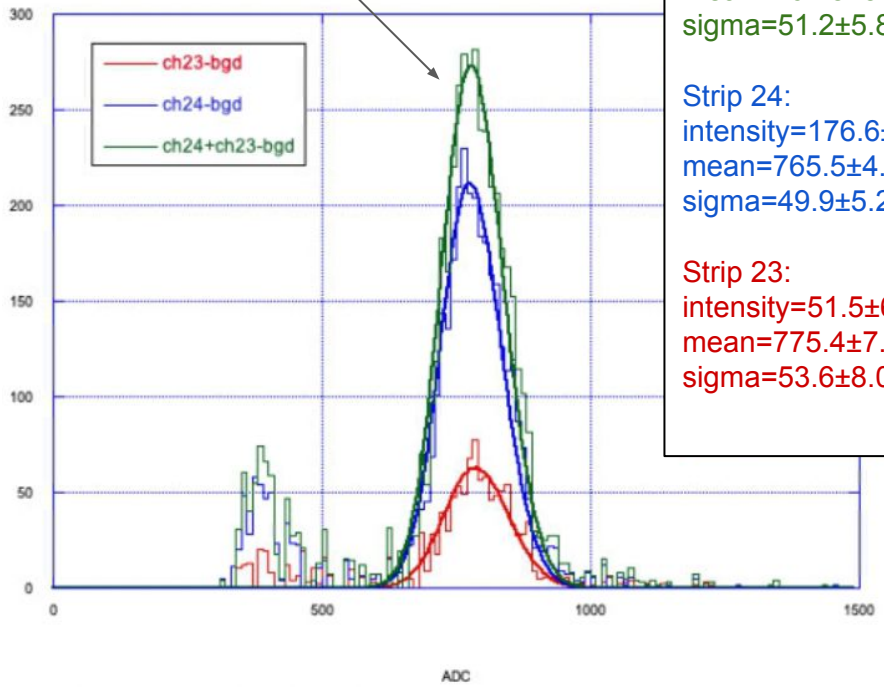
Strip 23+24:
intensity=227.1±21.2
mean=767.8±5.1adc
sigma=51.2±5.8 adc

Strip 24:
intensity=176.6±15.2
mean=765.5±4.6adc
sigma=49.9±5.2 adc

Strip 23:
intensity=51.5±6.3
mean=775.4±7.2adc
sigma=53.6±8.0 adc



Raw data



Gamma bgd subtracted on strips 23/24 (evaluated from spectra on strips 22/25/26)

Validation with CR muons

Assumptions:

Negligible charge attenuation due to electron lifetime

Uniform electric field in drift volume and in the surroundings of the source on the cathode (negligible space charge)

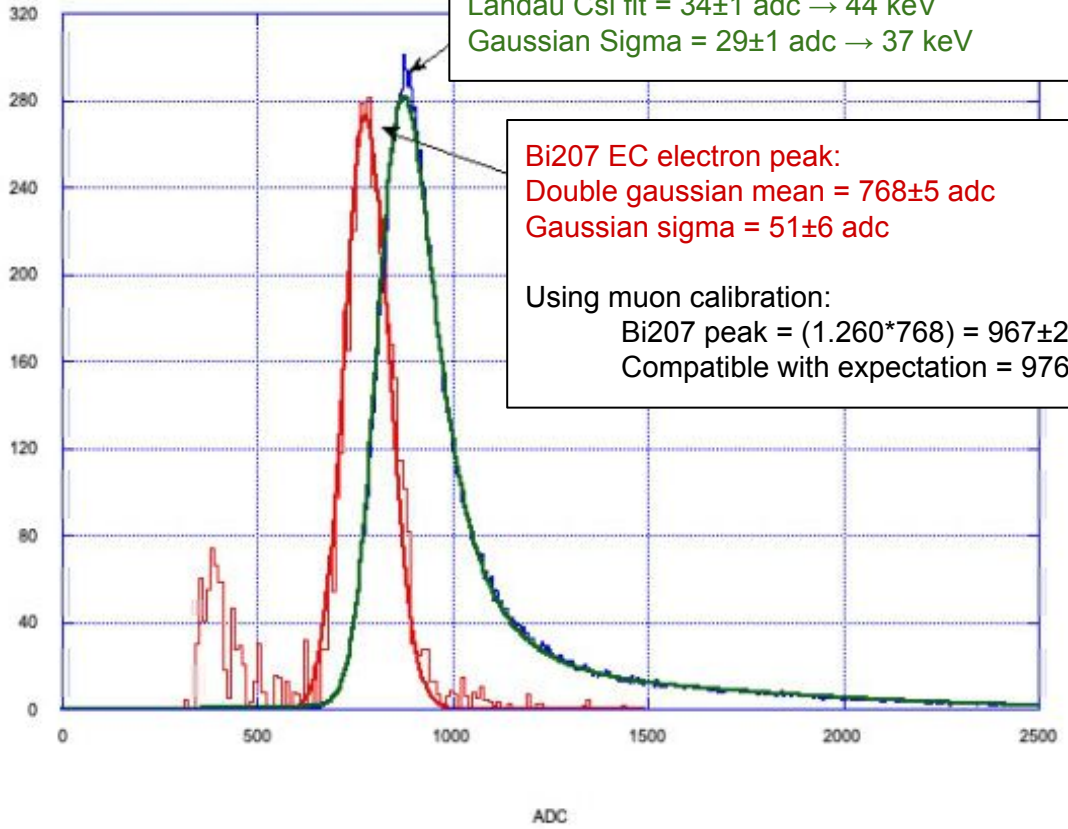
Same e-ion recombination for MeV electrons and mip muons

The error on the agreement between the EC peak energy evaluation and expectation is largely dominated by the uncertainties in the calibration procedure based on CR muons.

Average collection pitch for triggered muons = 6.6 mm
MPV for cosmic muons = 173±0.05 keV/mm
MPV*pitch=1140±30 keV
Landau MPV fit = 898±1 adc
→ *Calibration = (1140/898) = 1.260±0.035 keV/adc* ←
Landau Csi fit = 34±1 adc → 44 keV
Gaussian Sigma = 29±1 adc → 37 keV

Bi207 EC electron peak:
Double gaussian mean = 768±5 adc
Gaussian sigma = 51±6 adc

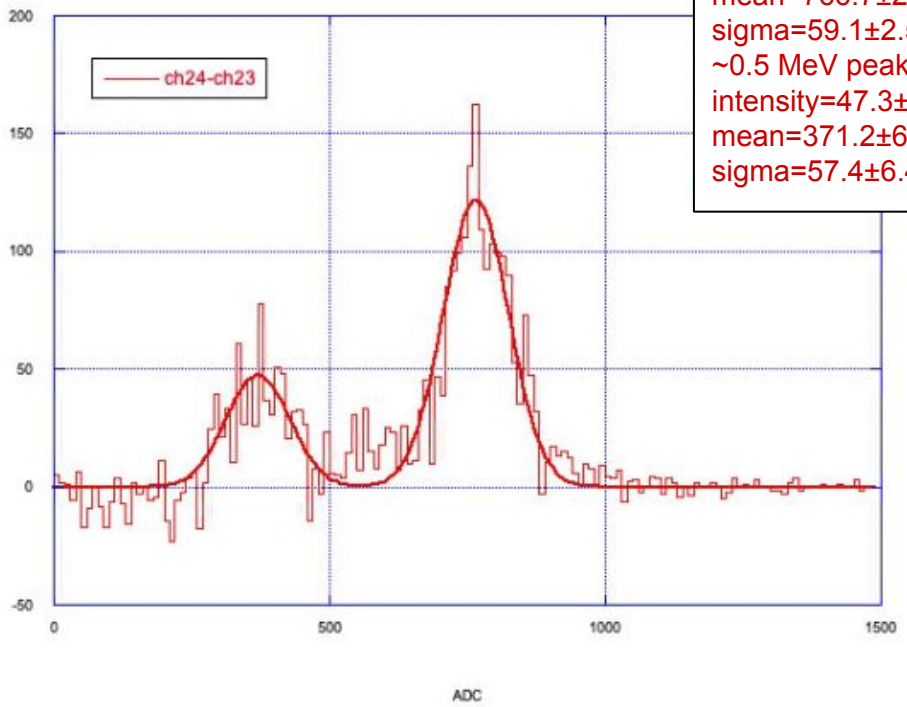
Using muon calibration:
Bi207 peak = (1.260*768) = 967±28 keV
Compatible with expectation = 976 keV



Source spectra

Expected peak at ~500 keV seems also to be visible at the correct position and intensity

(more statistics required and maybe lower data selection threshold)



~1 MeV peak:
intensity=121.4±4.5
mean=766.7±2.5adc
sigma=59.1±2.5 adc
~0.5 MeV peak
intensity=47.3±4.6
mean=371.2±6.4adc
sigma=57.4±6.4 adc

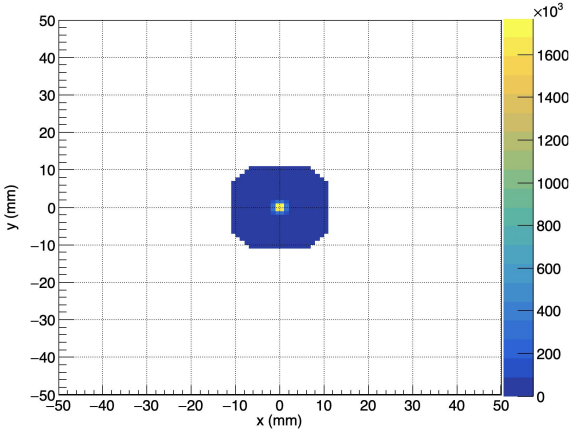
MC validation in progress

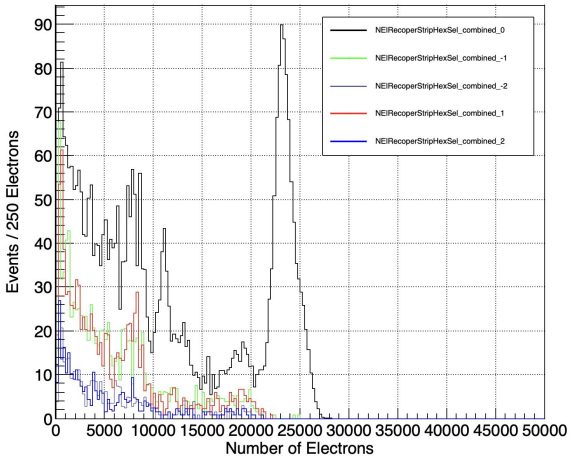
Generation with GEANT:

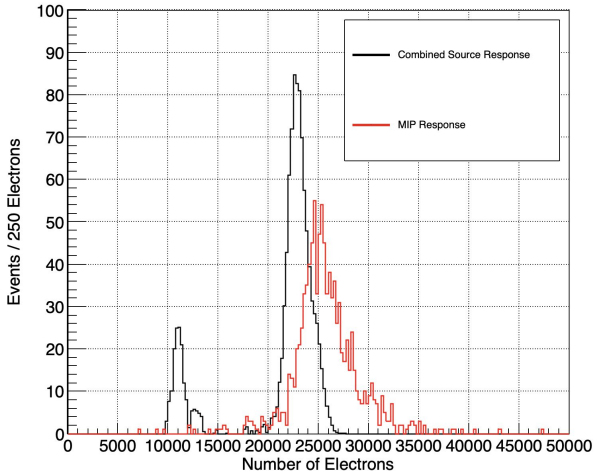
- All Bi207 source decay processes included
- Horizontal 1 GeV muons running at 45° with respect to collection strips
- Electron ion recombination included
- Infinite purity
- NO detector energy resolution

Analysis: same selection cuts as for data

- Consider the charge only if it falls within the hexagonal area constrained by the induction strips.
- Collect the charge in the central collection strip and the two neighbor strips either way.
- Subtract the gamma BG evaluated on adjacent strips (as for data)







Further steps in the source analysis

Monte Carlo validation

Extension of data analysis to the whole data taking period

Search for data with less good LAr purity (but similar noise conditions) to observe a Bi207 EC peak shift toward lower energies

Investigation of the role of electronic noise in the peak identification and reconstruction

Thanks to our 182 lab team!

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