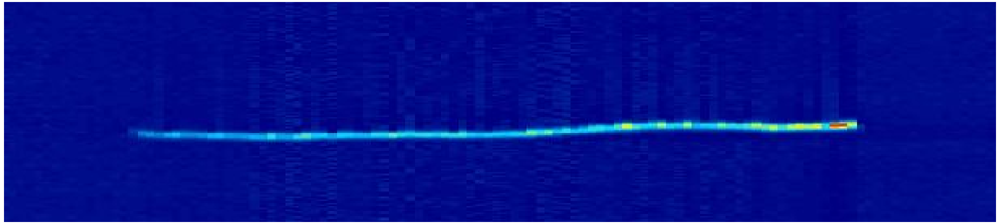
Pion Capture at Rest

Mark Ross-Lonergan (Hi!)
LArIAT Analysis Summit, 30th Sept 2016

Pion capture at rest



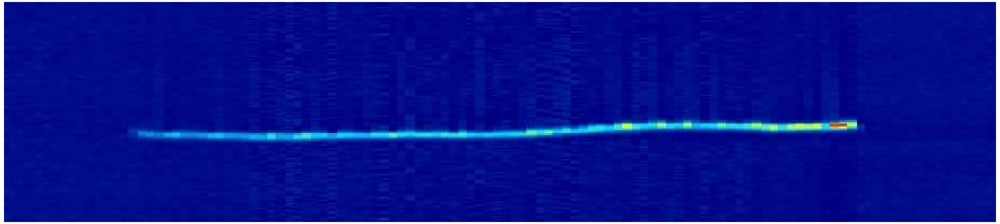
A negative pion which stops in a material has the chance to be electromagnetically captured forming a pionic-atom.

As the Pion spirals inwards, eventually there is a non-zero overlap of the pion wavefunction with nucleons of the host nucleus, and is absorbed.

The rest mass of the pion is then converted into kinetic energy for the nucleons. This is not a democratic process! Only a “few” nucleons share in the kinetic energy.

Depending on internal final state interactions and re-absorption, between 0 and ~5 nucleons are ejected from the nucleus and **no** final state pion

Not just neutrons.



Capture on Lithium

Table 7
Branching ratios per stopped pion (%) for ^{6}Li.

Ref.	nn	np	nd	nt	pp	dt	pt	tt	cc[c]
[166]	41(17)	11(3)							
[166][a]	69(28)	23(6)							
[179]	51(9)	13(2)	14(2)	8.6(13)					4.2(5)
[178][b]	66(2)	6.5(6)	11(1)	5.2(5)	0.02(1)	0.80(5)	0.4(2)	0.18(1)	1.9

[a] Finer angular resolution.
[b] For comparison normalised to 91%, the total yield per π stop [179].
[c] Coincidences between any two charged (p, d, t) particles.

Capture on Deuterium

Table 4
Branching ratios for capture of stopped pions in (liquid) deuterium. Data from Highland et al. [79] and MacDonald et al. [80].

Channel	Branching ratio (%)
$\pi^- d \rightarrow nn$	73.75(27)
$\rightarrow nn\gamma$	26.06(27)
$\rightarrow nne^+e^-$	0.181(2)
$\rightarrow nn\pi^0$	0.000145(19)

Capture on He

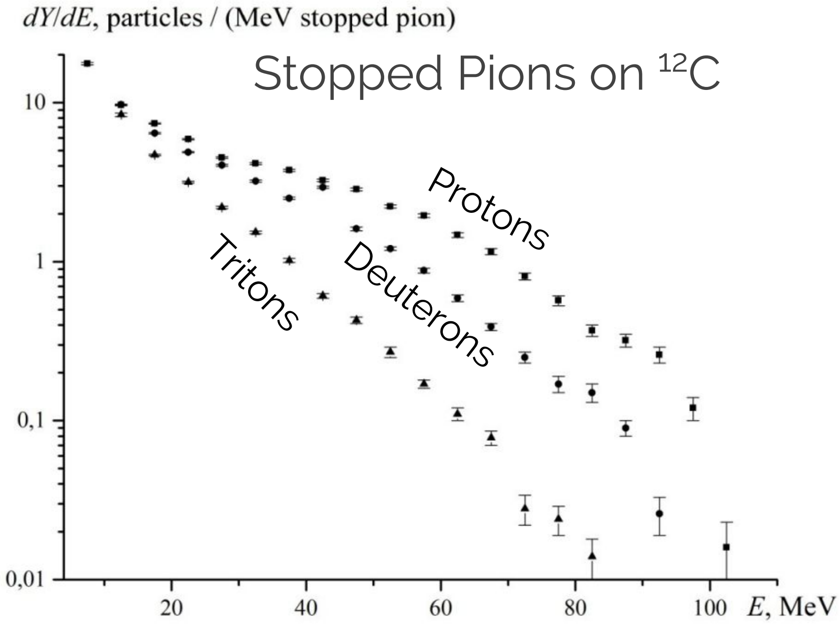
Table 8
Branching ratios for stopped pion absorption in ^{3}He.

Reaction	Branching ratios (%)				
	[184]	[111, 112]	[183]	[182]	[181]
$\pi^-\ {}^3He \rightarrow \gamma X$[a]	14.0 ± 1.3	10.5 ± 1.3	–	–	
$\rightarrow \pi^0 t$	17.8 ± 2.3	15.8 ± 0.8	–	12.8 ± 1.2	13.5 ± 2.3
$\rightarrow dn$	–	15.9 ± 2.3	15.9 ± 1.6	–	11.7 ± 1.8
$\rightarrow pnn$	–	57.8 ± 5.4	–	–	60.8 ± 4.0
$\rightarrow dn + pnn$	68.2 ± 2.6	73.7 ± 5.9	–	–	72.5 ± 4.2
$P(^3He)$	2.68 ± 0.13	2.28 ± 0.18	–	–	

[a] X = t, dn, pnn.

Pion Absorption in Light Nuclei, Weyer, 1990

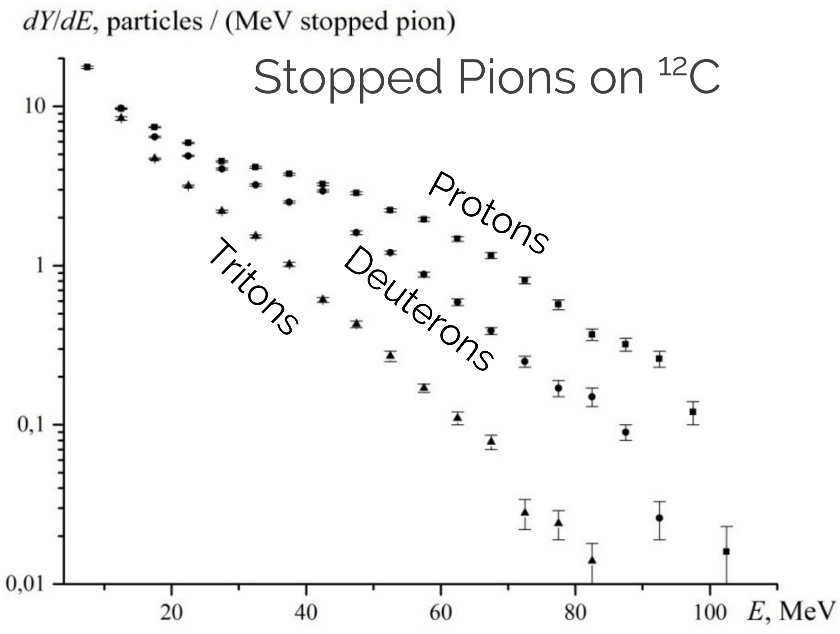
What would we see?



Yu.B. Gurov et al 2015

Fig. 1. Spectra of p (squares), d (circles), t (triangles) emitted in stopped pion absorption on ^{12}C nuclei.

What would we see?



Yu.B. Gurov et al 2015

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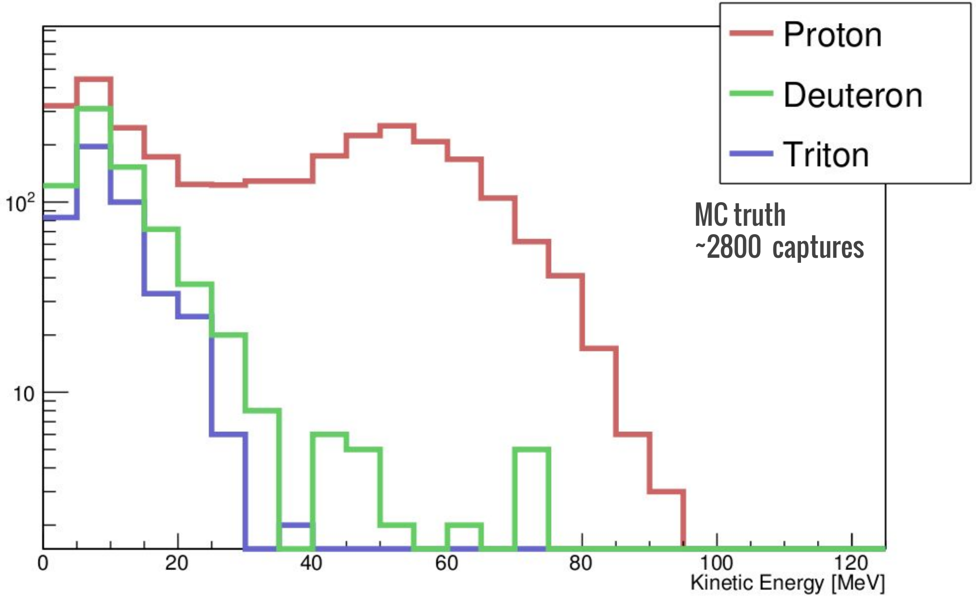
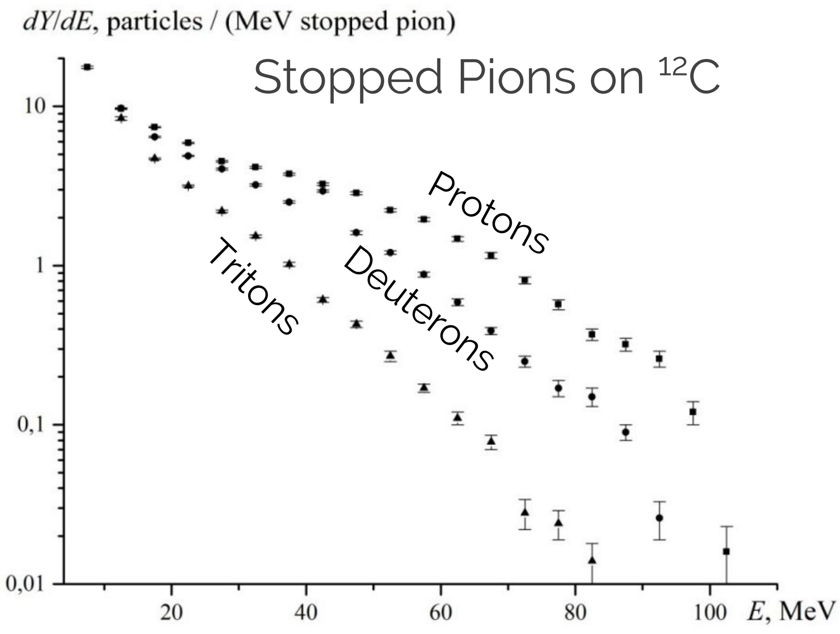
Stopped Pions in LAr



What would we see?



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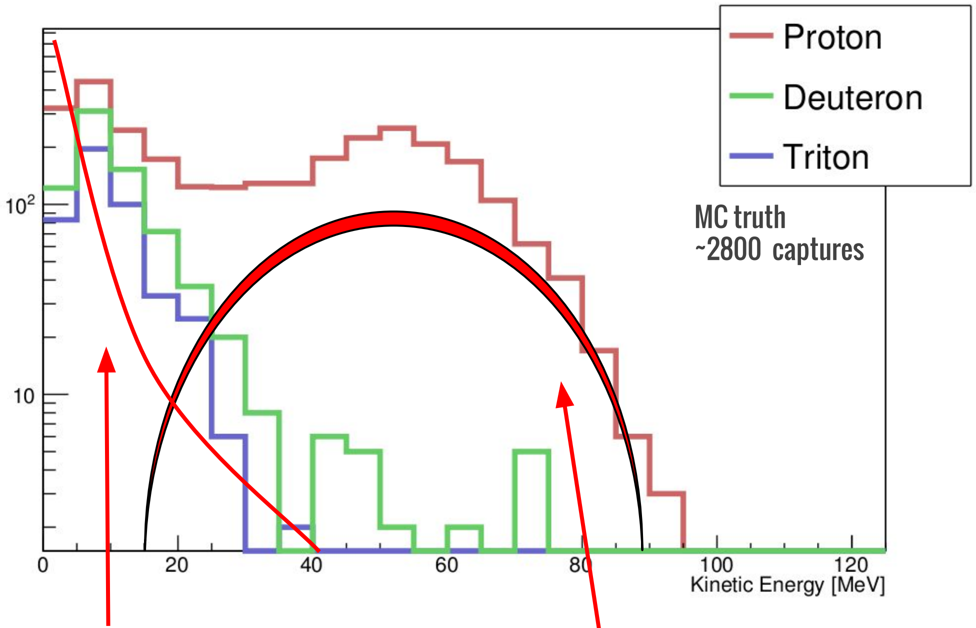
Stopped Pions in LAr



"Evaporation particles" that escape from the surface of the nucleus once thermodynamic equilibrium is established

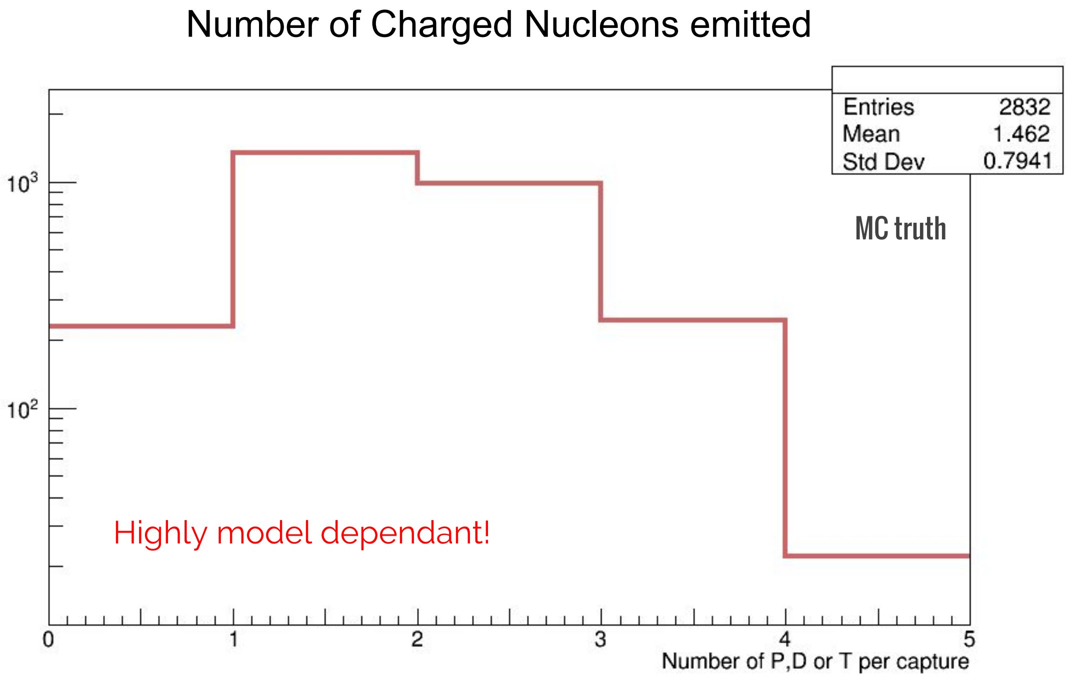
"Primary particles" formed directly after the absorption of pions by the intranuclear clusters

This is Geant4 generated by either

"CHIPSNuclearCaptureAtRest"

"hBertiniCaptureAtRest"

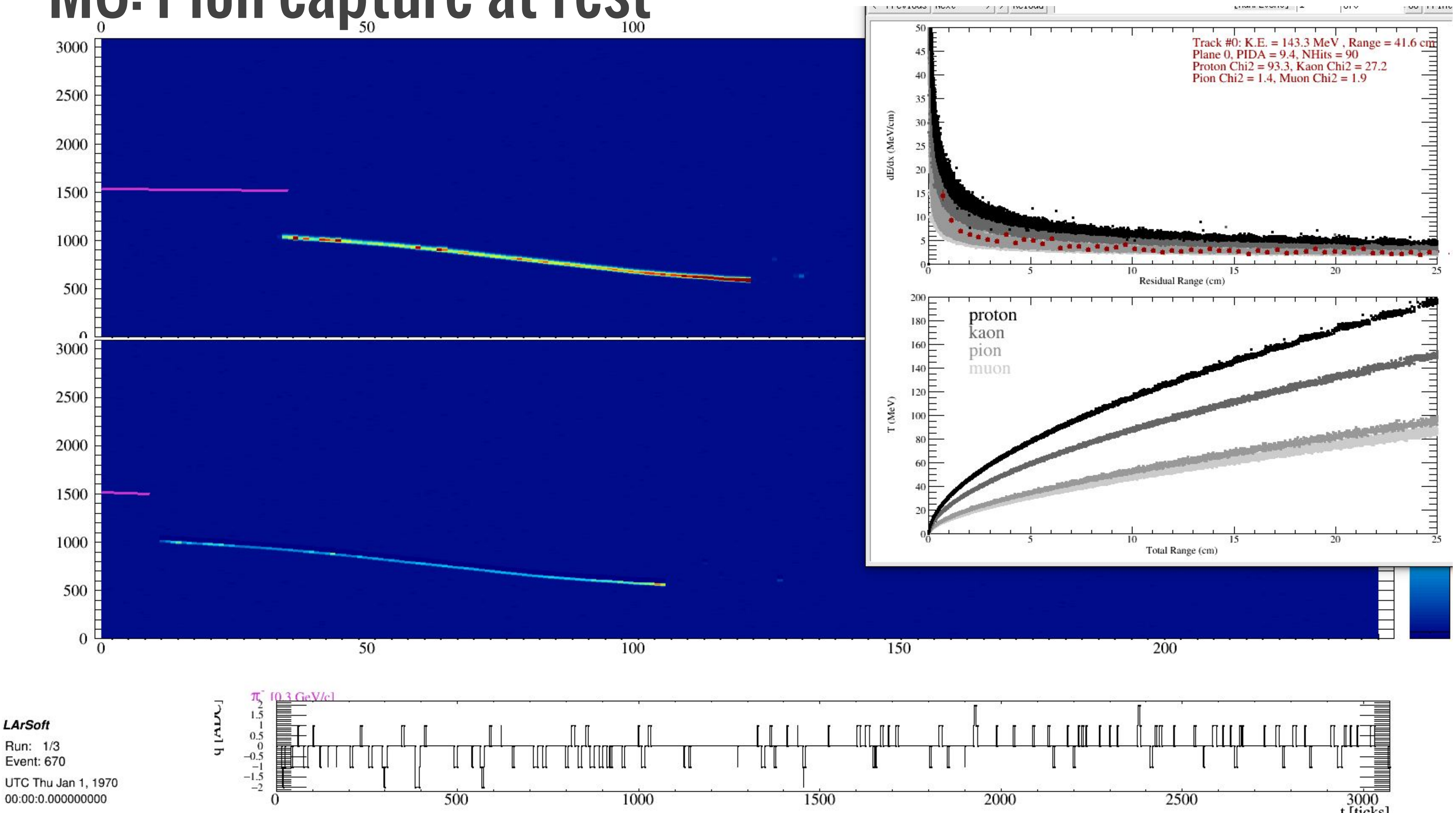
No pion capture on Ar data has been taken, MC is mostly tuned from Carbon, Silicon and Calcium measurements



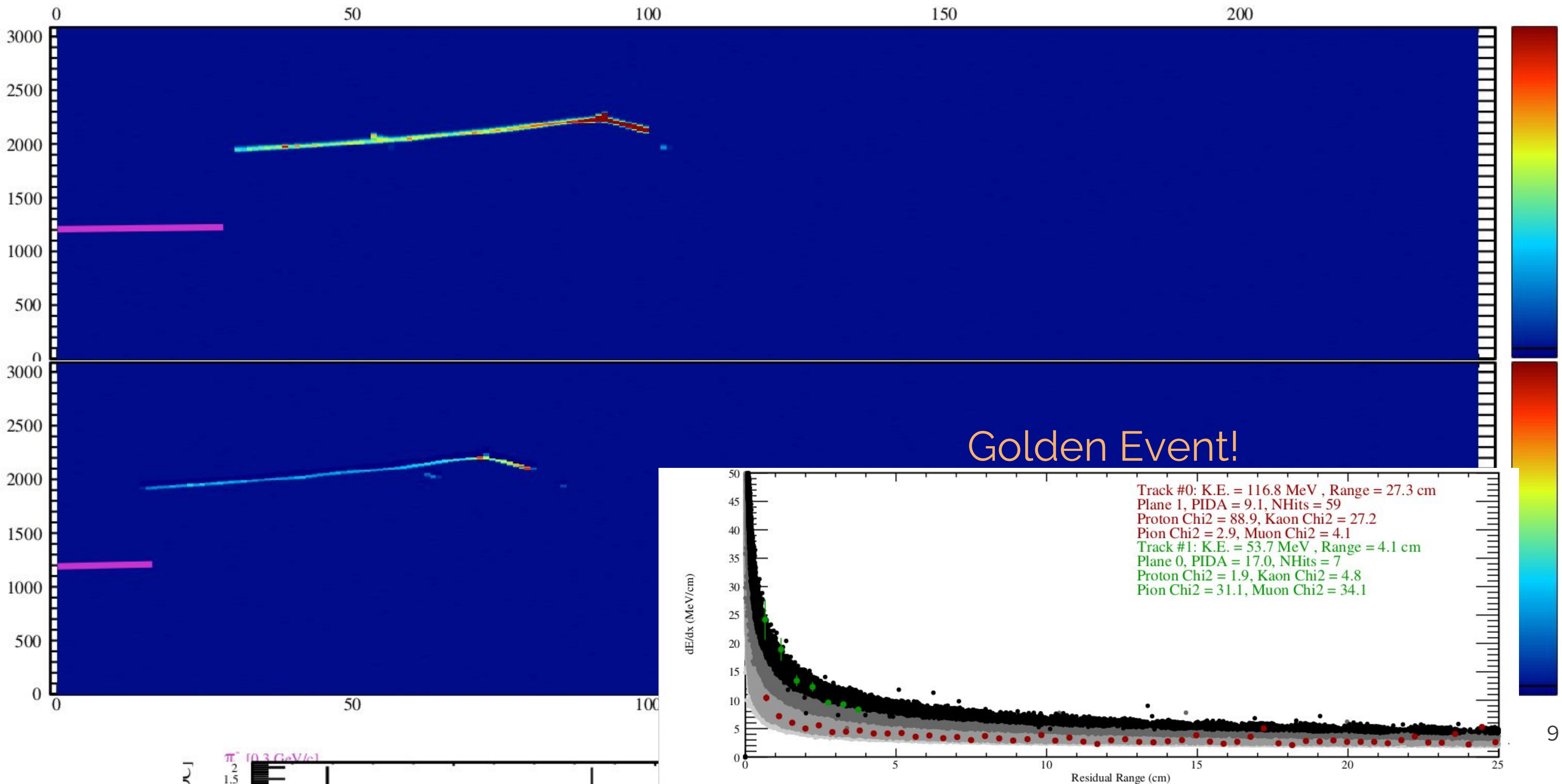
I am modifying Irene's "StoppingTracksFilter_module.cc" to select all stopping Pions that undergo capture.

Ran over both MC and some run 1 data to get a feel for Pi Minus capture

MC: Pion capture at rest

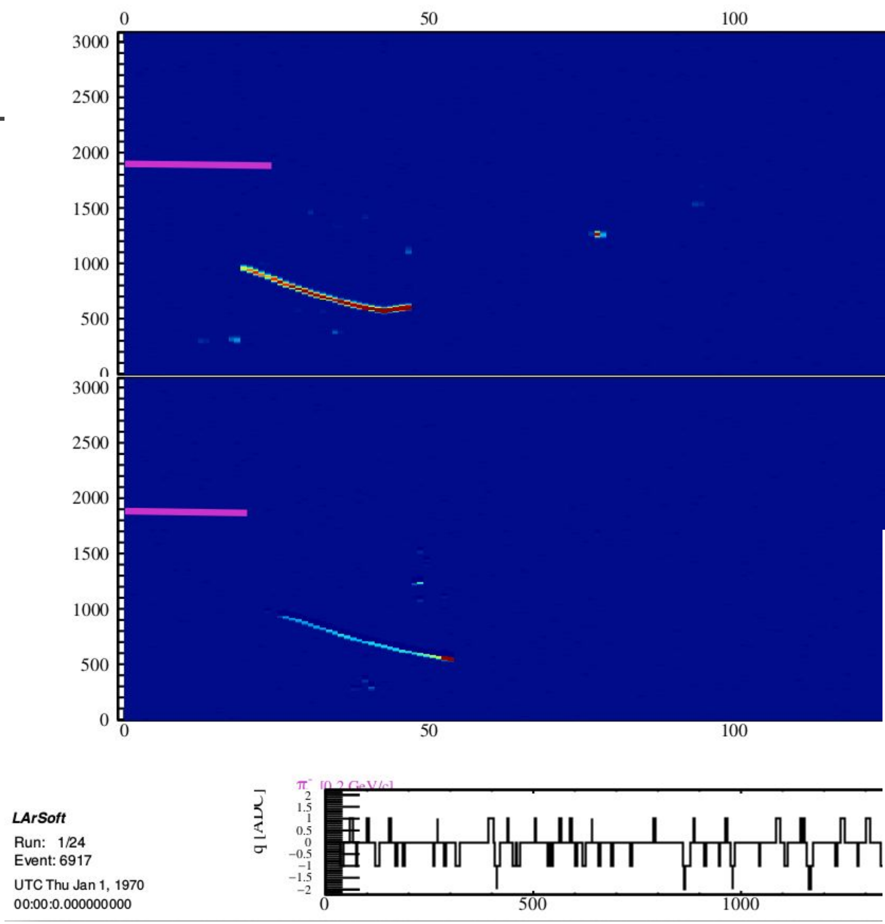


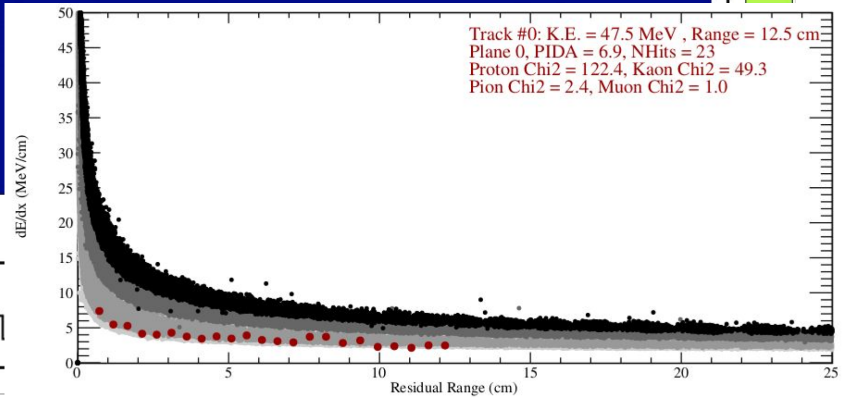
MC: Capture + 1 proton (reconstructed KE ~ 71 MeV)



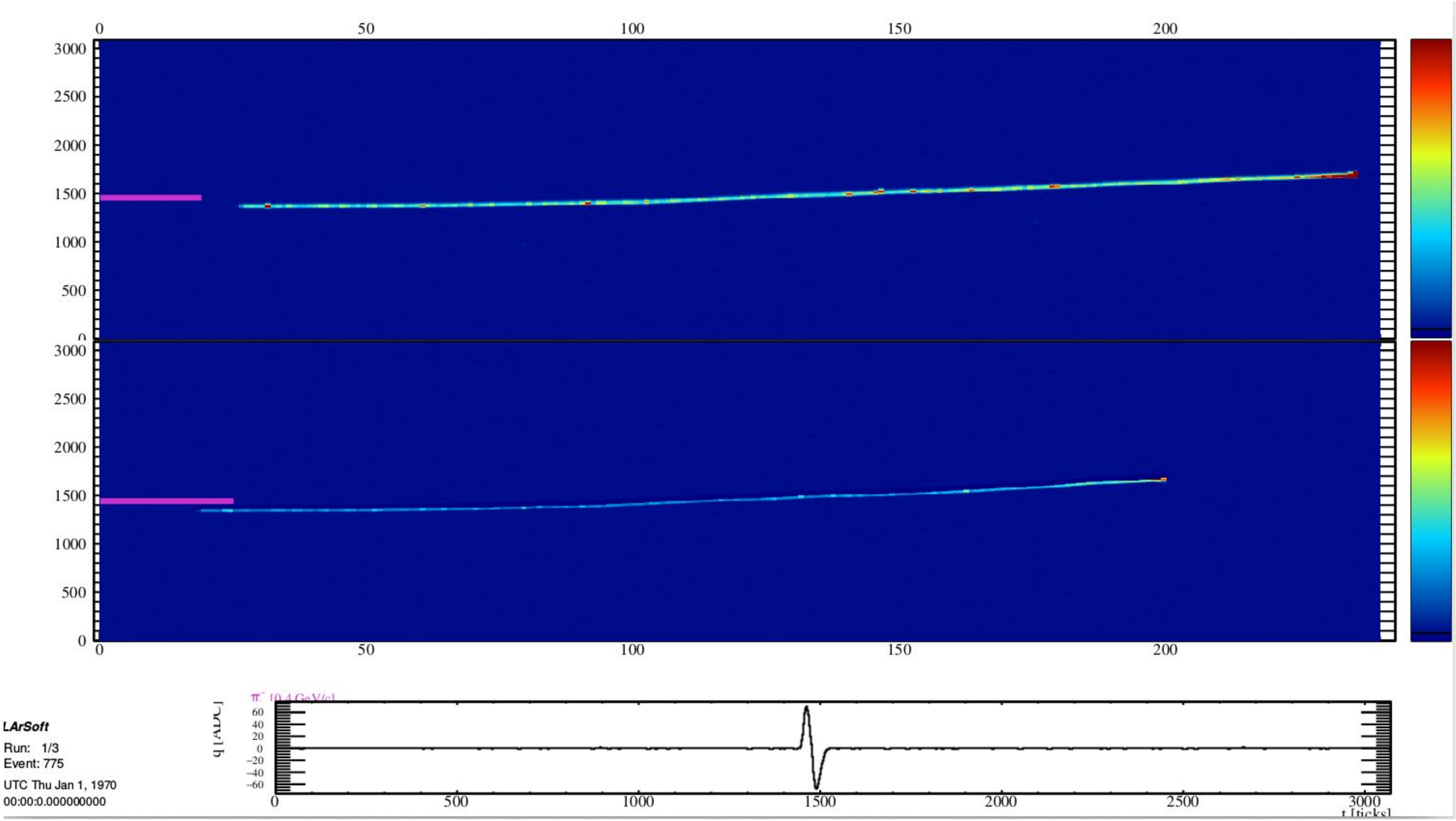
MC: Deuteron (not reconstructed, KE ~40 MeV)

–





MC: Triton (not reconstructed, KE truth = 44 MeV)



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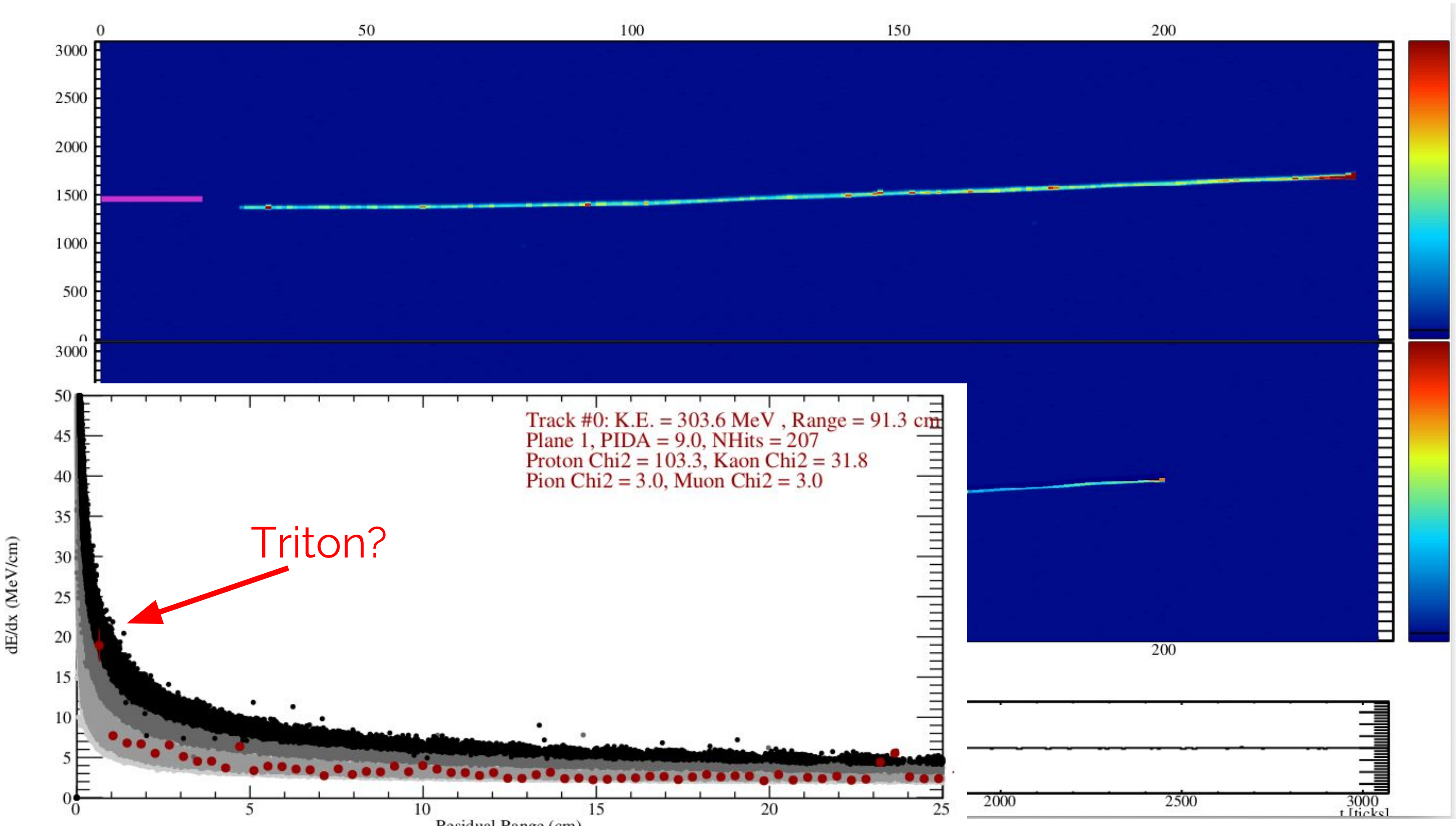
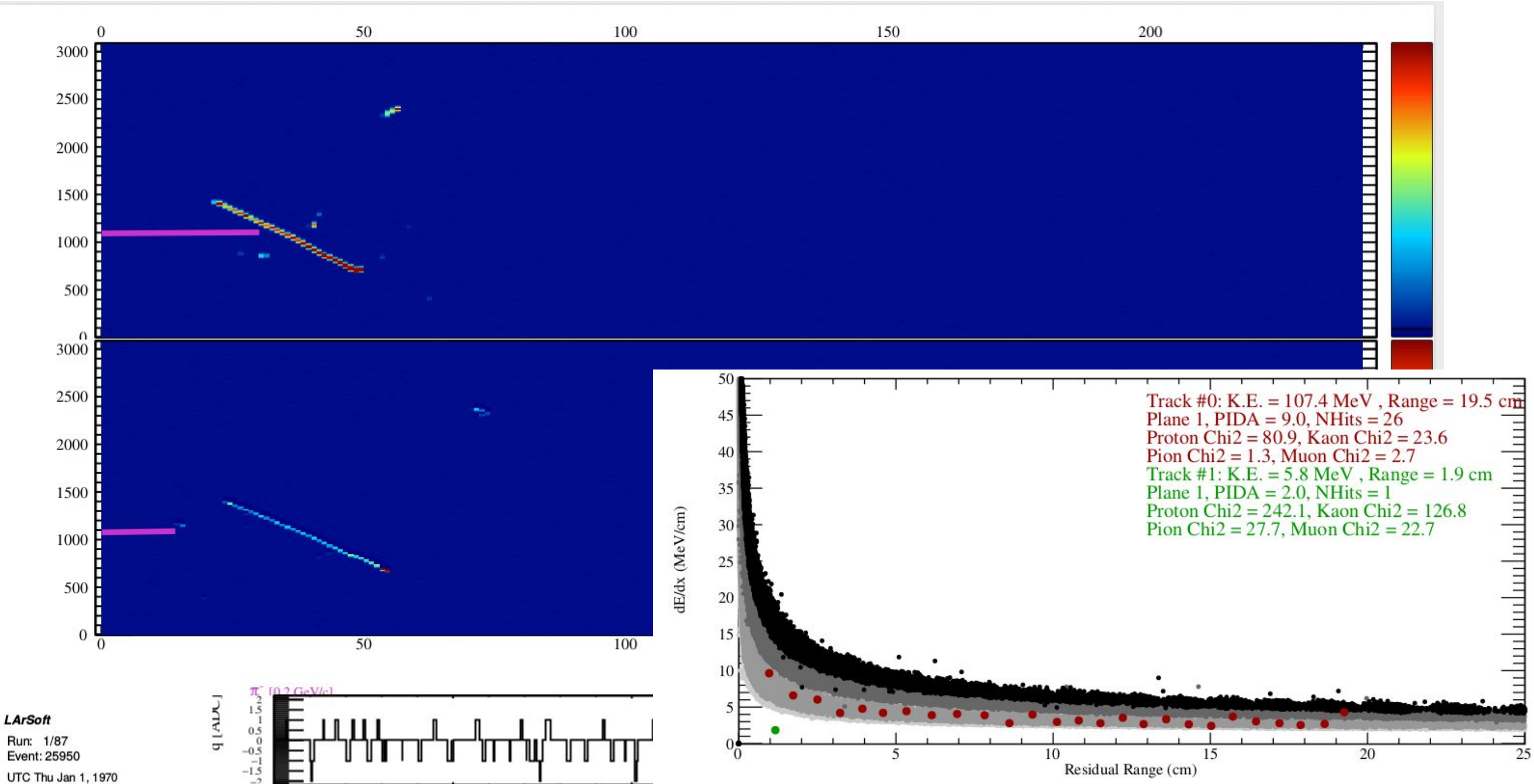
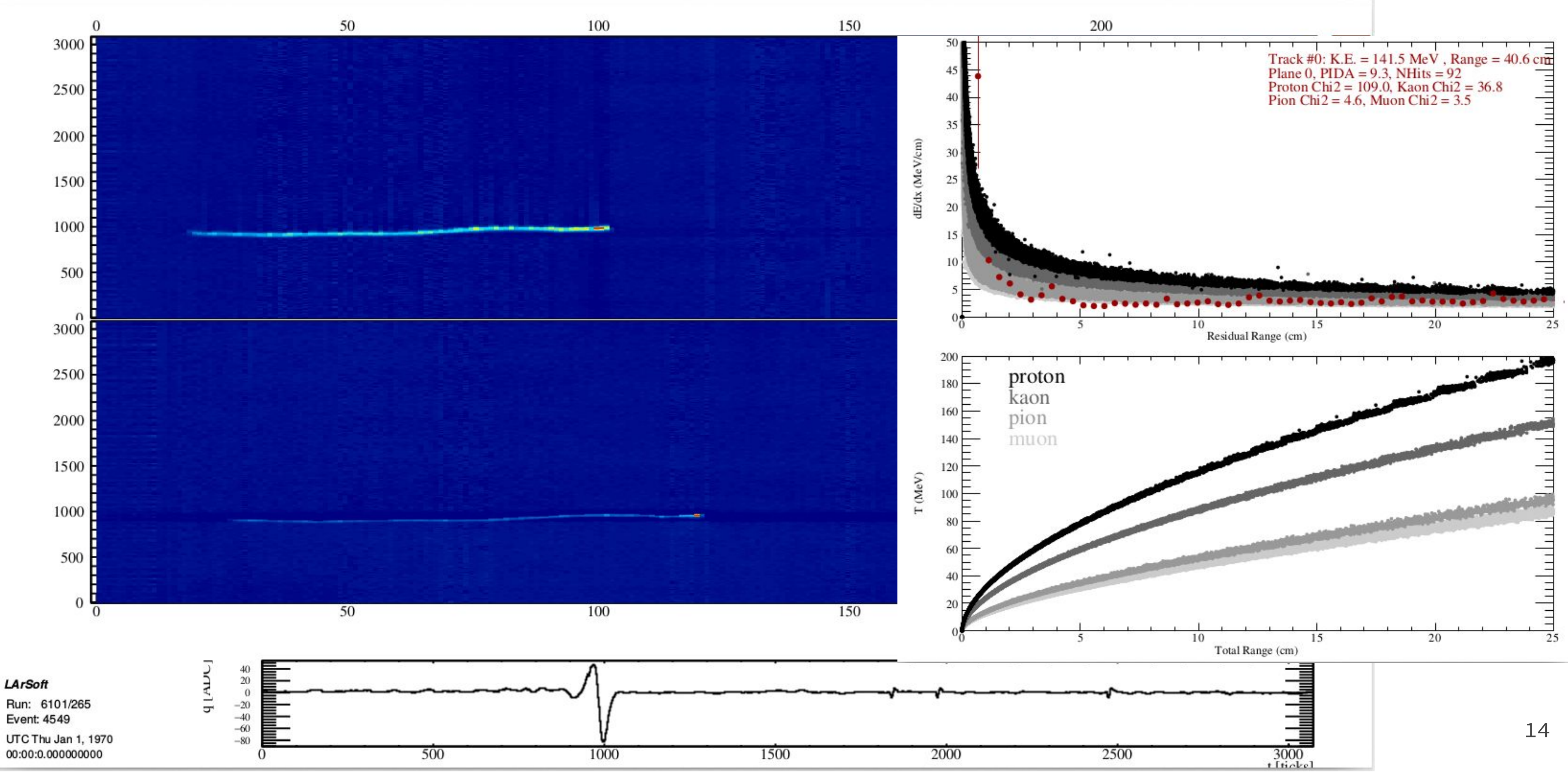


MC: Triton (not reconstructed, KE truth 41 MeV)



Data Run 1: Pure capture? no visible nucleons



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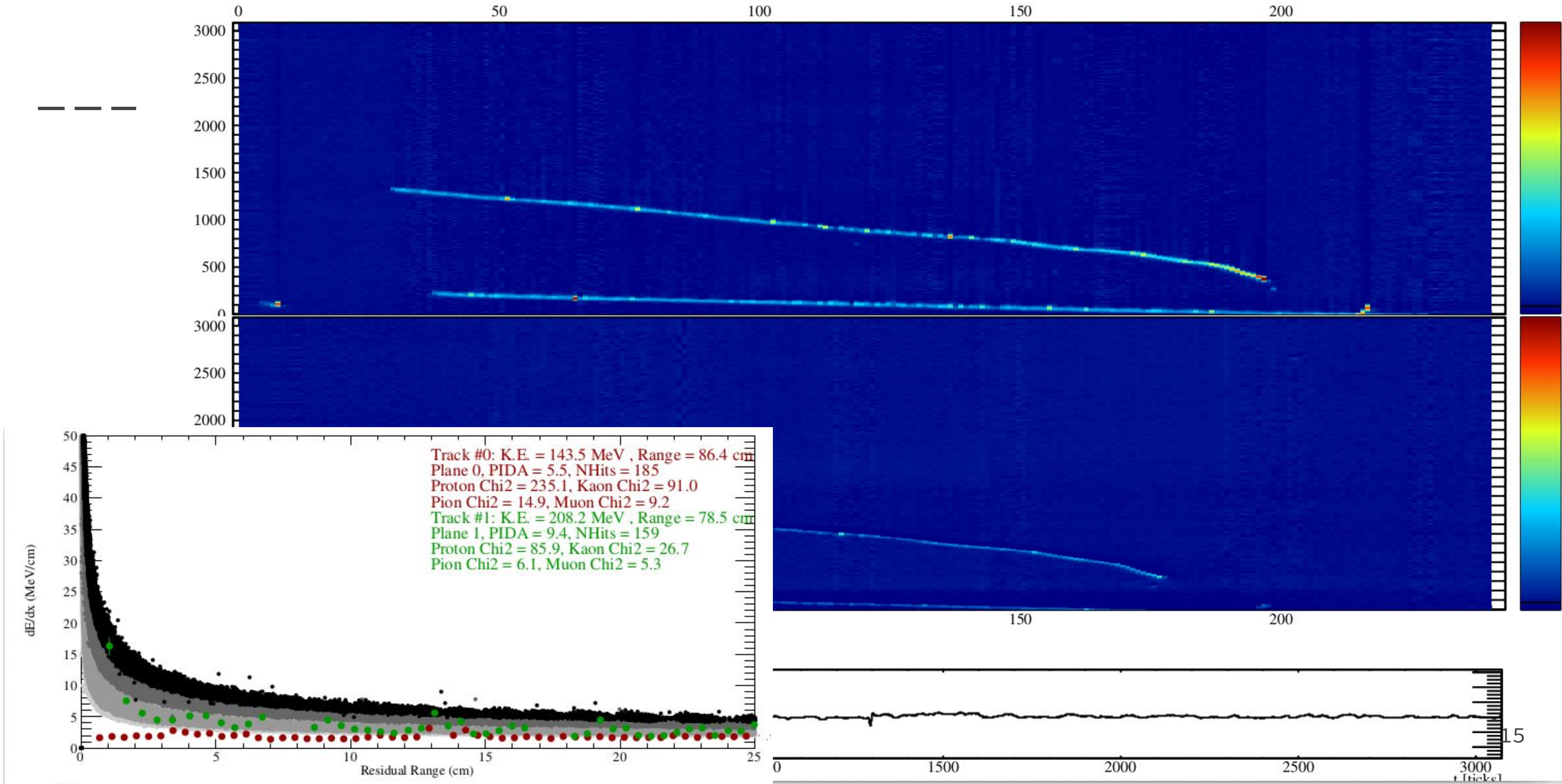
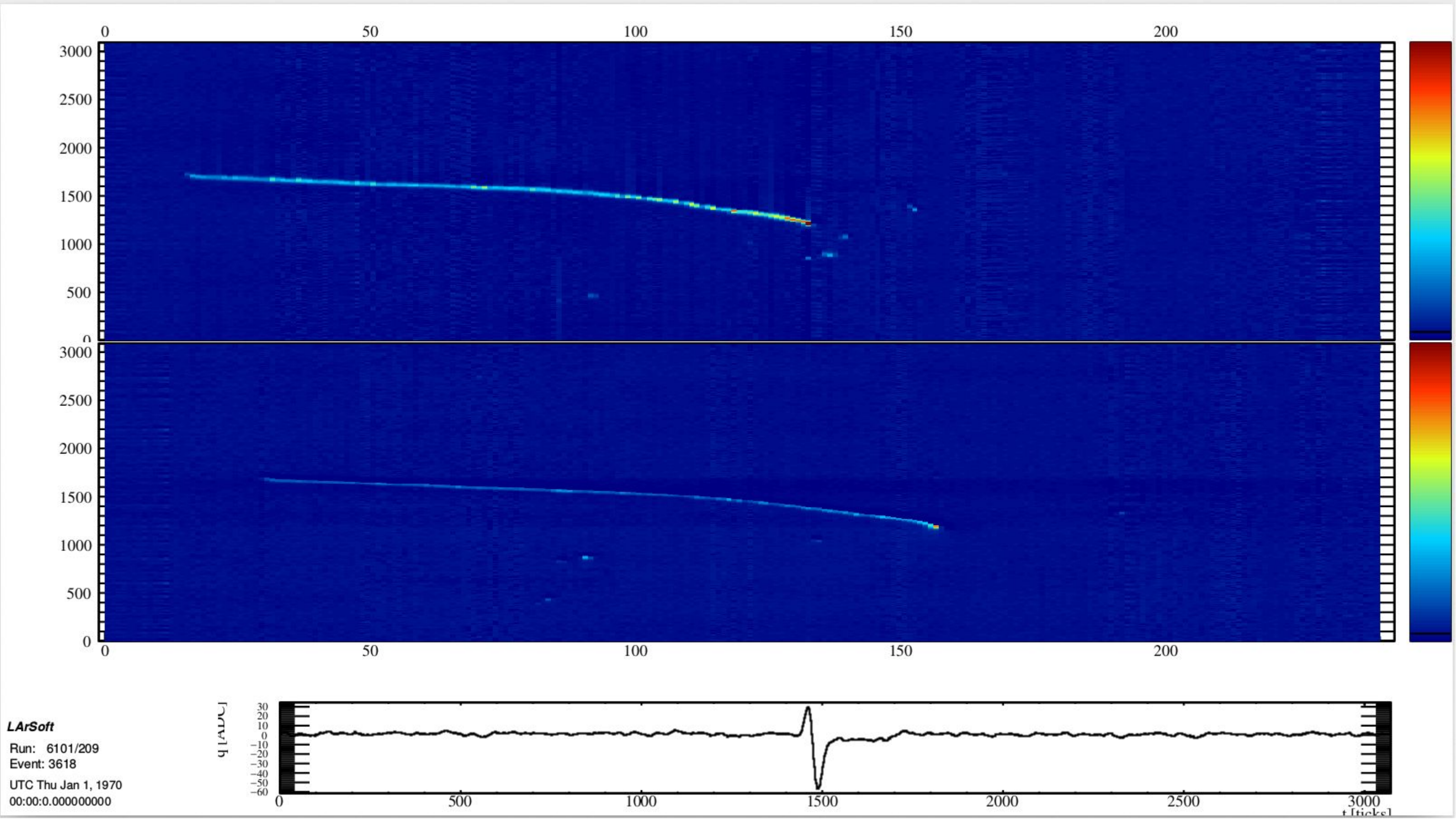


Data Run 1: Capture + neutrons? Incorrect reco



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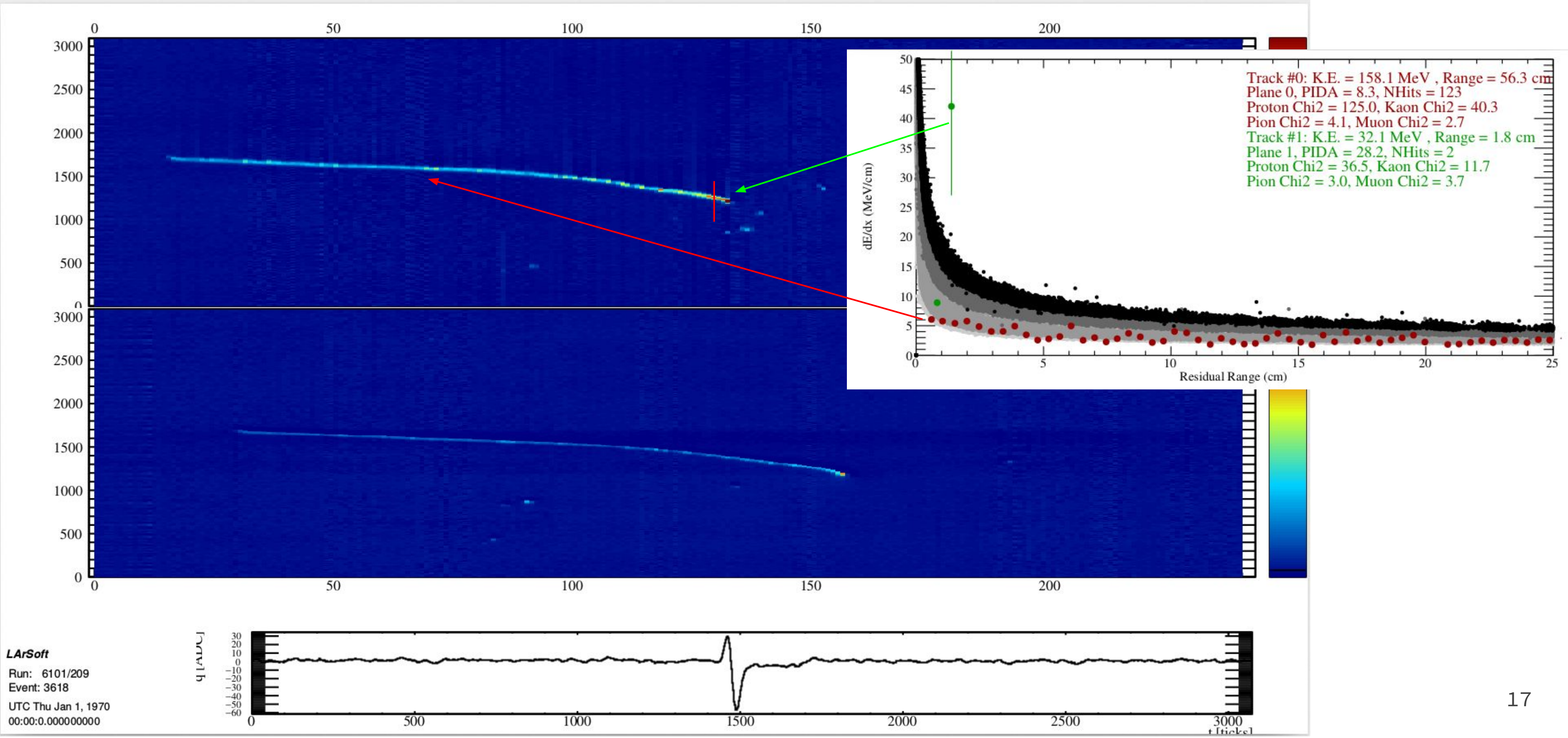
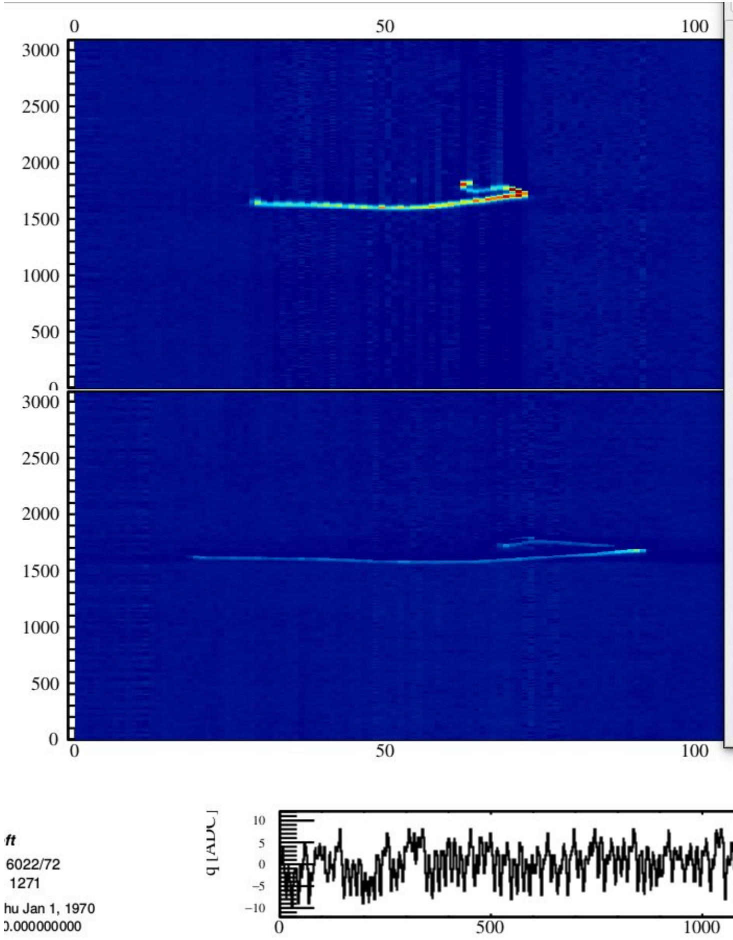
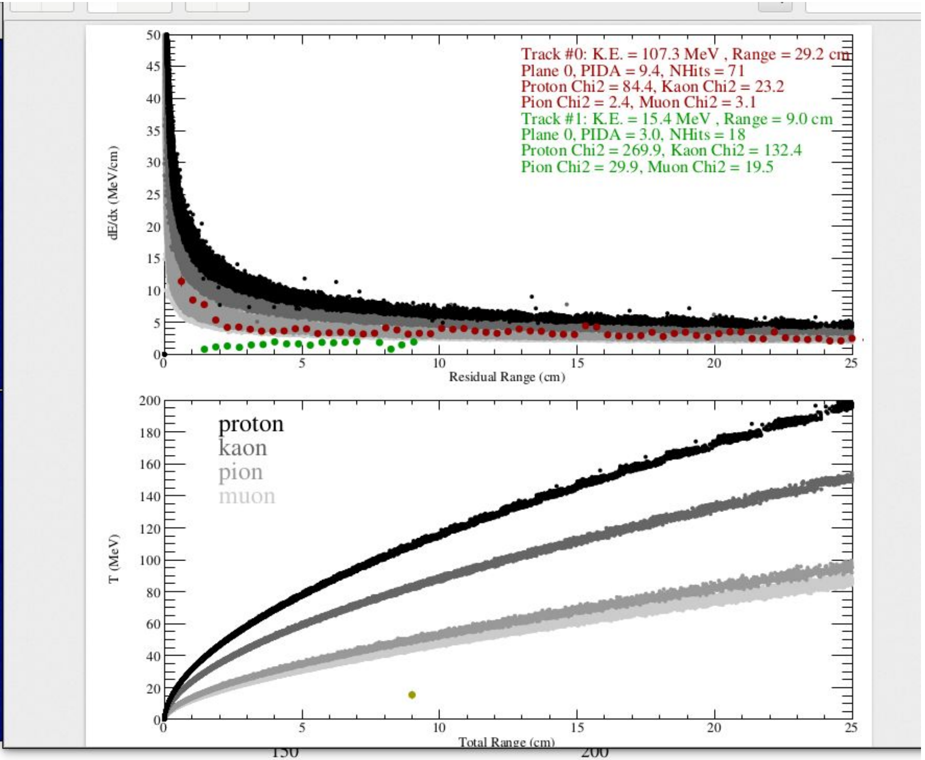
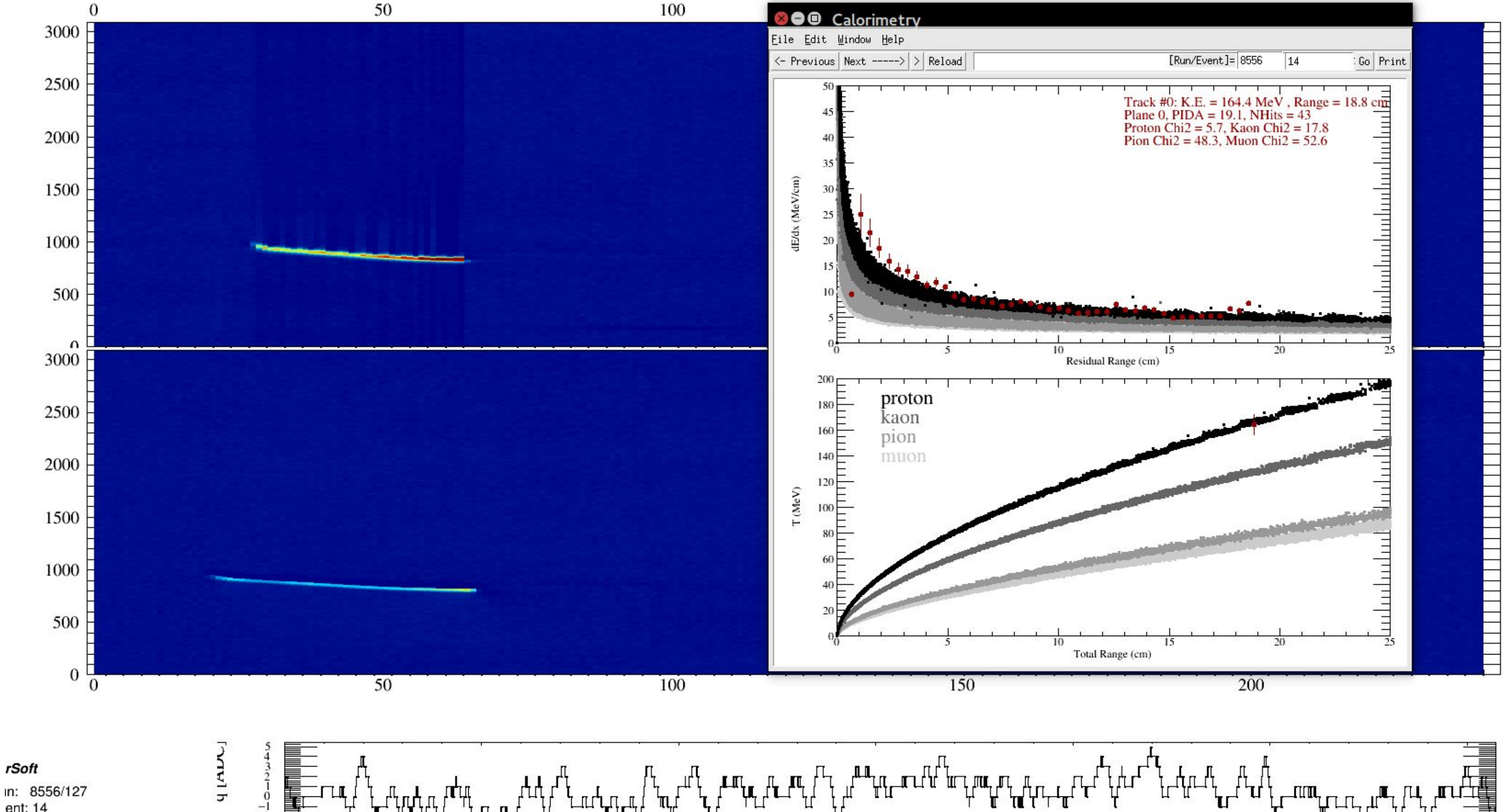


Data: Backgrounds, Stopping Muons and/or Pion Decay?



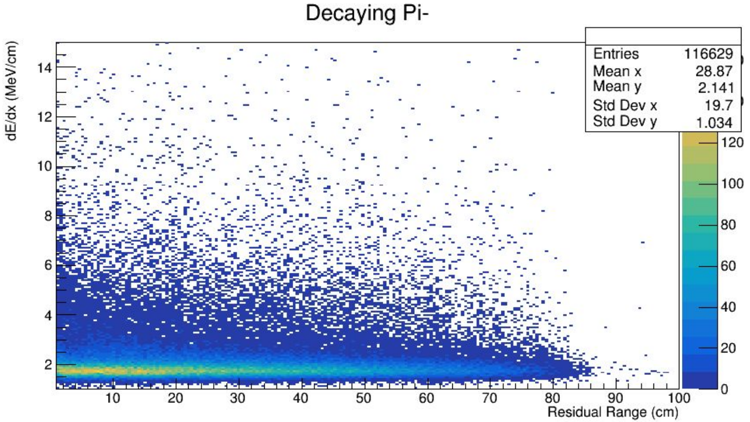


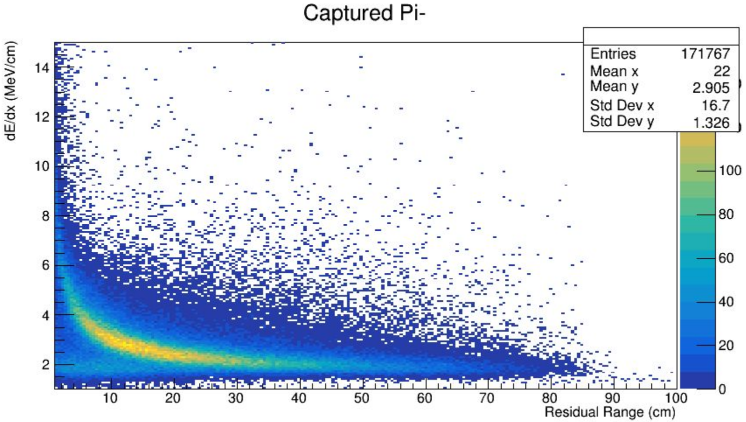
Data: Backgrounds Stopping Protons



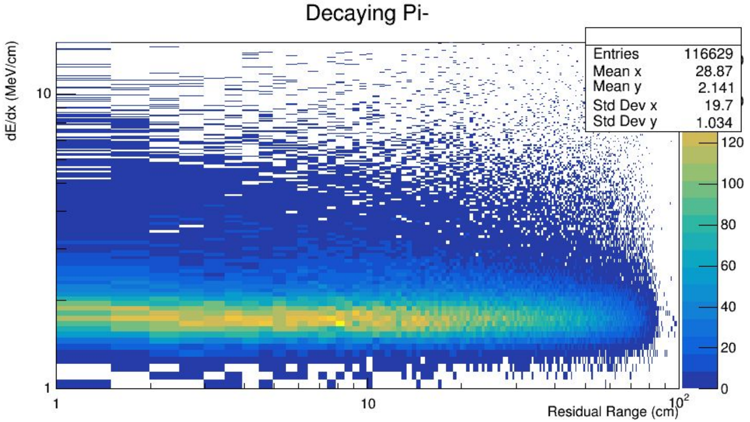
1st Background, Pion Decay or Capture?
Simulated 120,000 piMinus events, Energies 500-1000 MeV

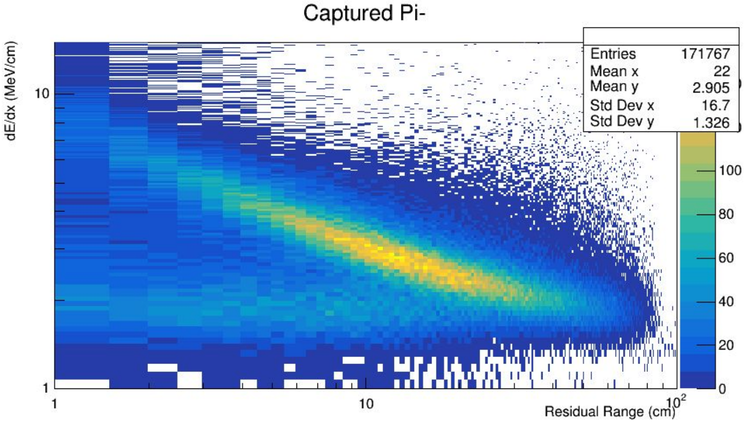
1249
Decays
~1.3%





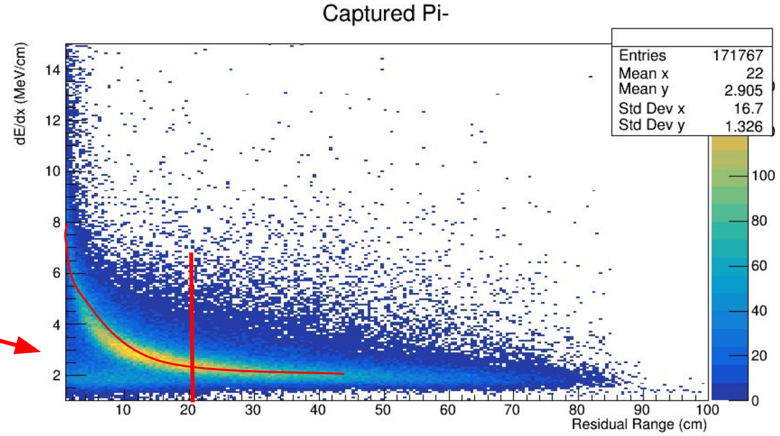
2832
Capture
~2.8%

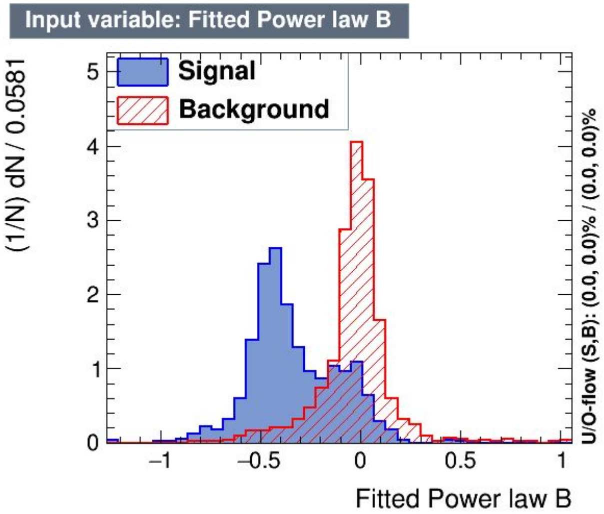


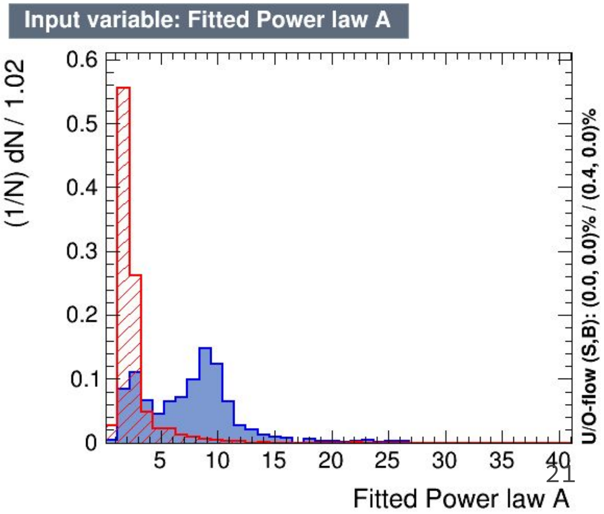


A) Calorimetric Information

Fit Bragg peak to a power law $dE/dx = A\, rr^{-b}$







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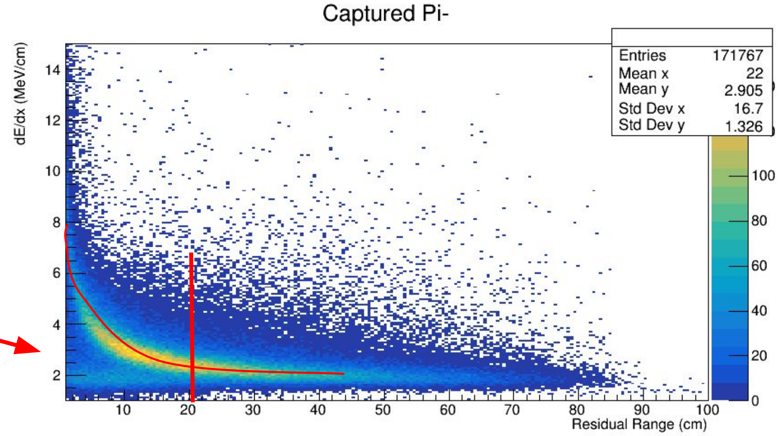
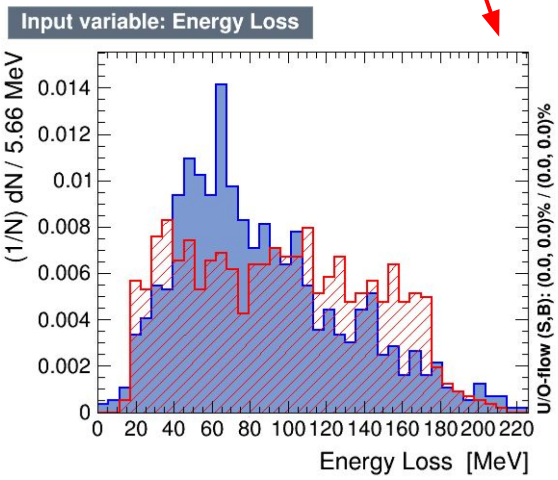
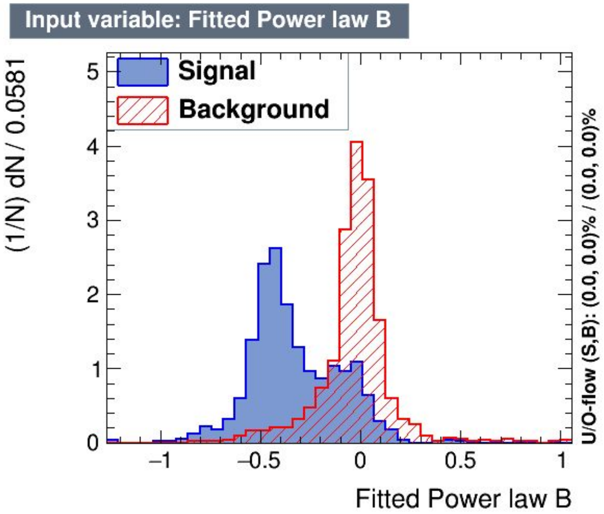
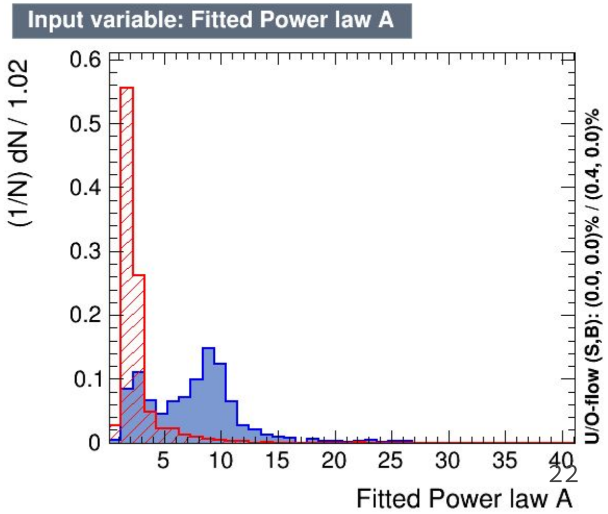


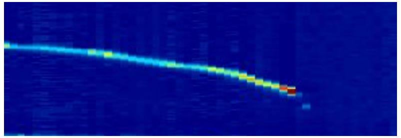
Total energy loss of track





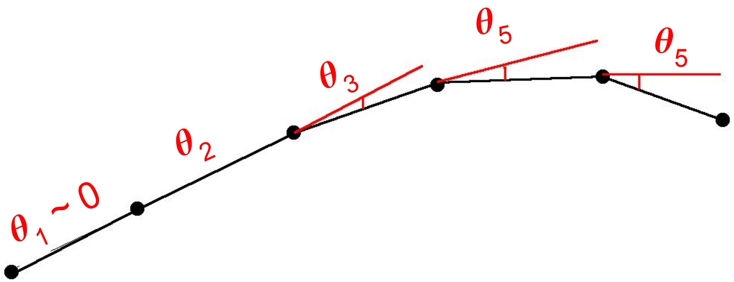


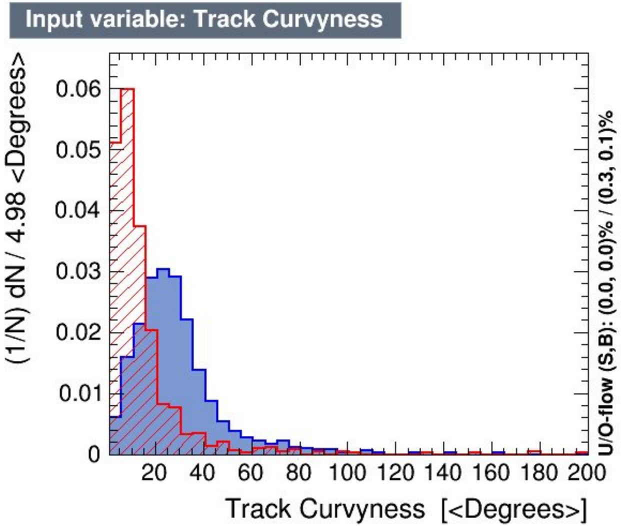
B) Topological Information



Track Curvyness: Sum of angles between successive 3D spacepoints

trkCurvyness = Sum θ_i





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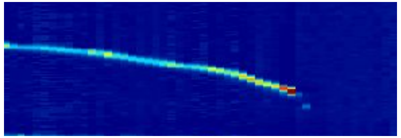

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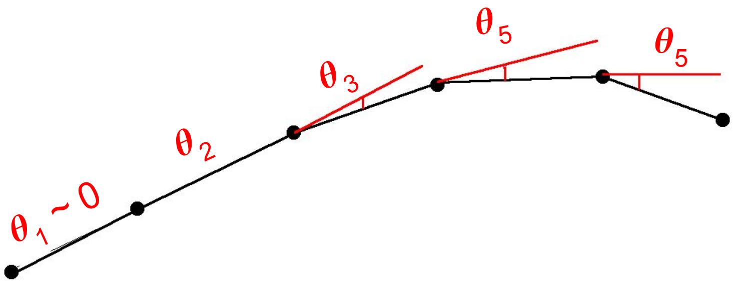
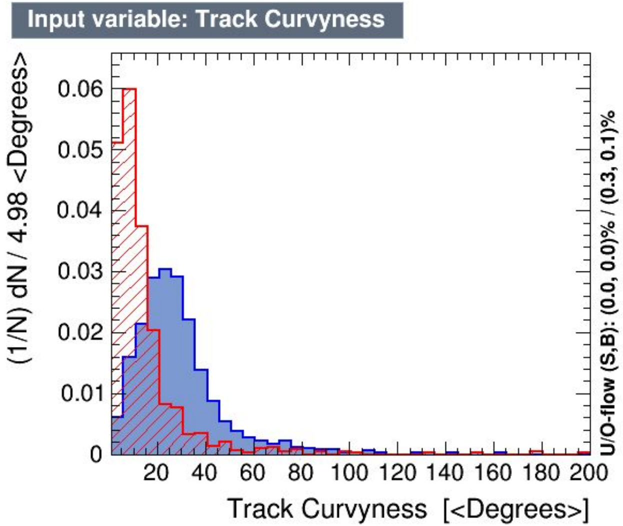
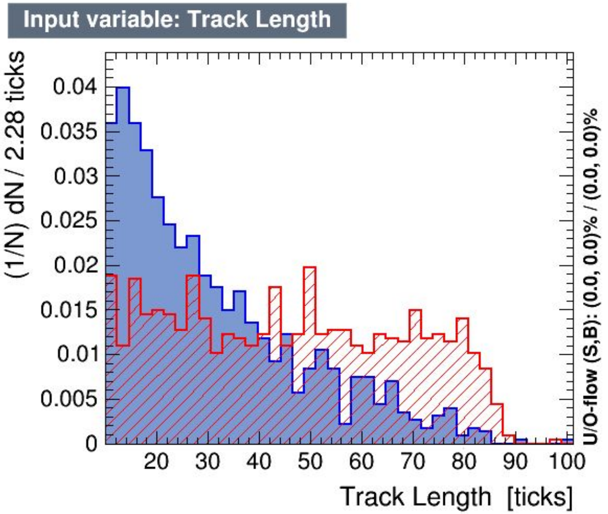
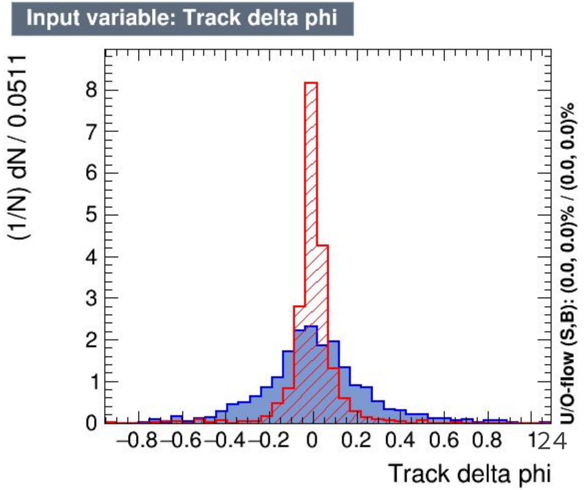


Track length, correlated to Energy loss

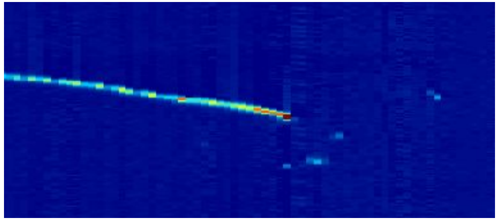






B) Topological Information

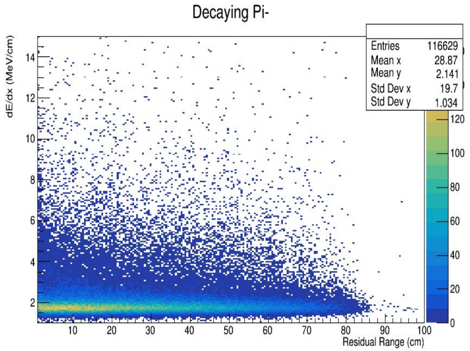
A **LOT** more powerful topological information can be used

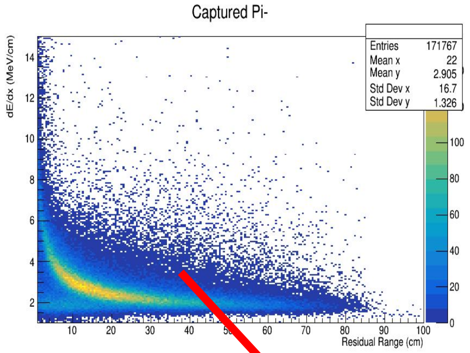


1) Are there any daughter tracks reconstructed? If not Capture more likely.
2) Now many?
3) Are the daughters muon/electron like? (indicative of decay)
4) or Proton/ Deuteron like? (indicative of capture)
5) Are there unassociated hits surrounding track endpoint, not easy but some correlation to neutron activity?

Currently working on adding these as discriminators between capture and decay

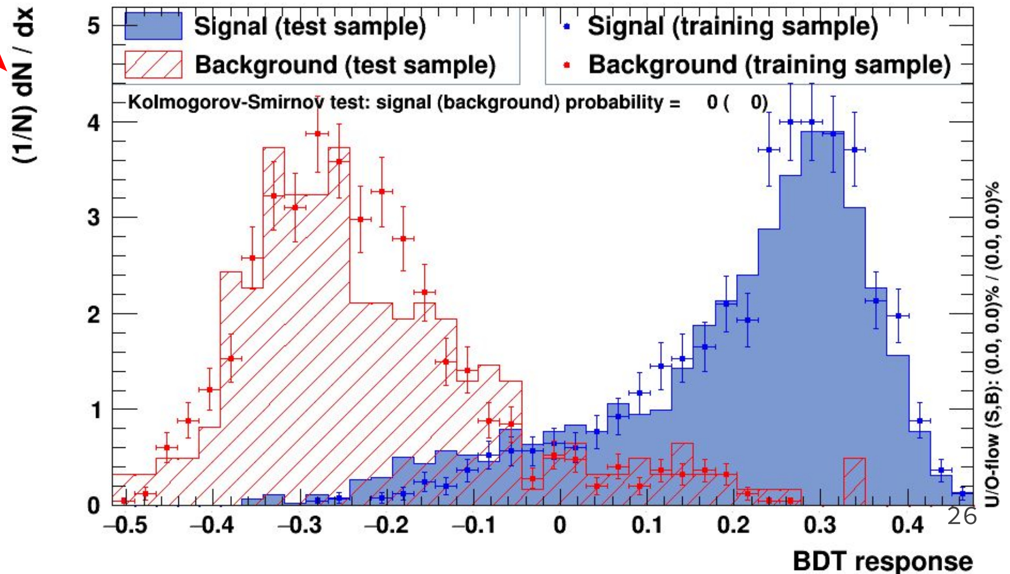
Boosted Decision Tree





In sample, 2832 Capture and 1249 Decay events

Currently training on 1000 events signal and background events. 800 Trees considered with Maximum depth of 4.



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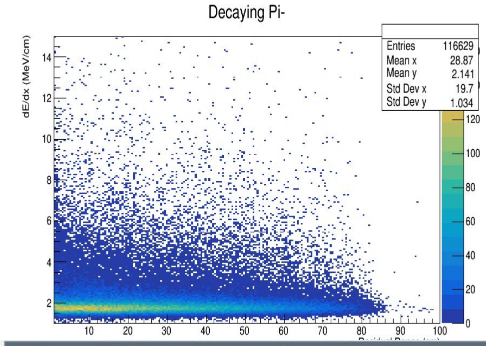

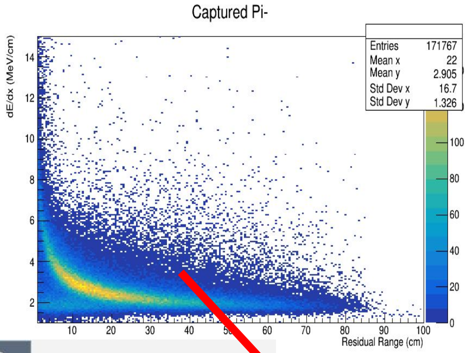

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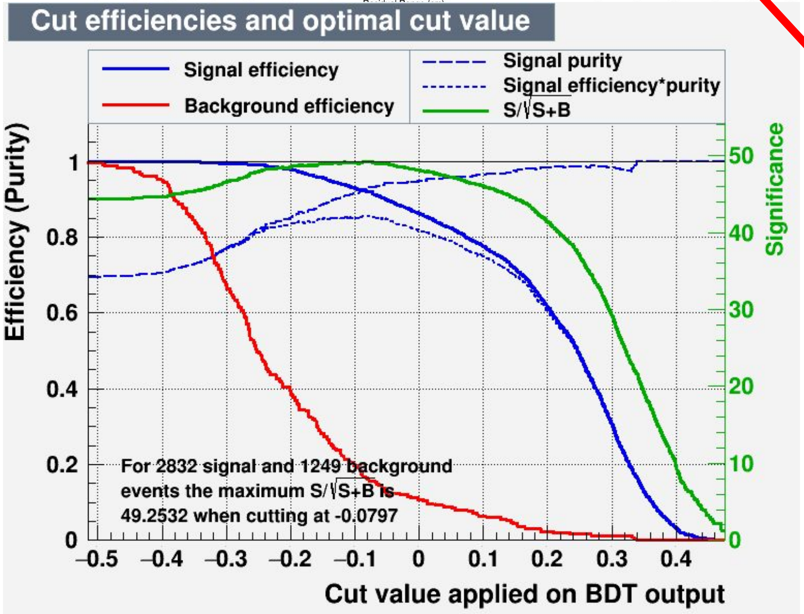

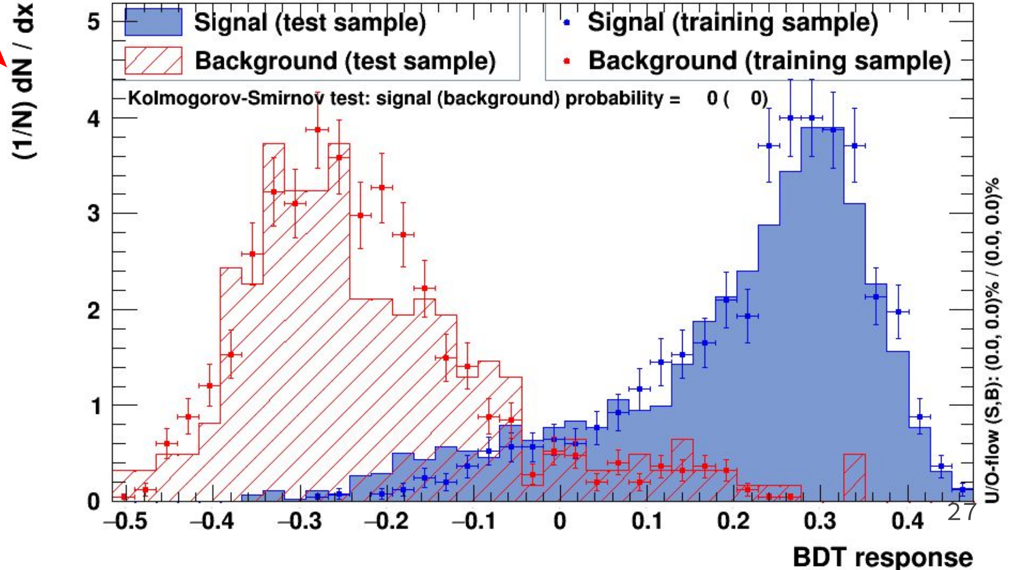

Next steps.

1) More statistics in MC!
2) Implement other topological cuts. PIDA/Liklihood ID of daughters
3) Investigate a few oddities, anomalously large dE/dx at low residual range
4) Other potential backgrounds, scatterings and Muon decays?
5) Tailored reconstruction, tuned to get final state protons/deuterons
6) Statistical charge identification via capture/decay ratio.
7) ...Suggestions welcome!

Backup

Charged Particles from Capture of Negative Pions by Nuclei. Yu. G. BunvAsuov et al 1971 (not necessarily stopped)

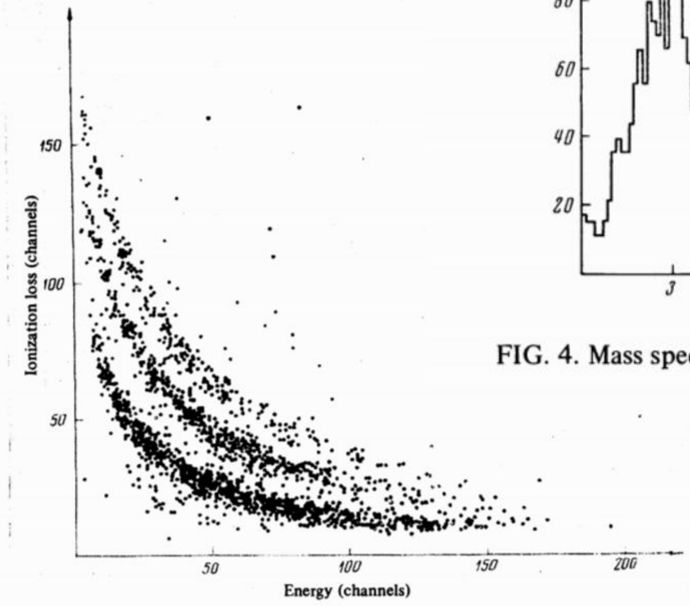

FIG. 3. Distribution of charged particles as a function of ionization loss and total energy for ^{12}C.

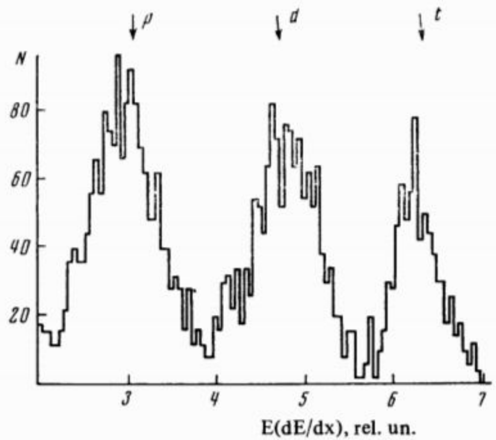

FIG. 4. Mass spectrum of charged particles for ^{9}Be.

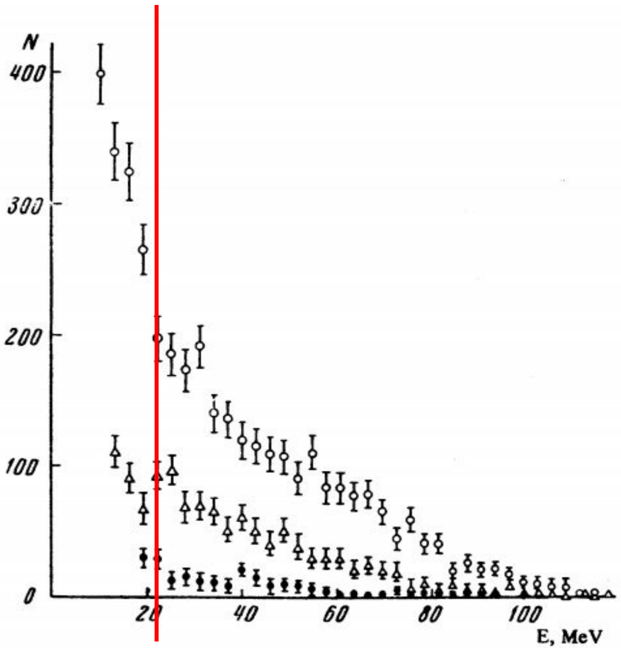

FIG. 5. Energy spectra of protons, deuterons, and tritons obtained in capture of pions by ^{32}S nuclei: ○—protons, △—deuterons, ●—tritons.

Argoneut 1306.1712.pdf

PIDA
proton->Deut->Trit
17 -> 25 -> 32(? estim)

34+ is a trit?