Energy Deposits and Thresholds in TPC.

Setup

```
<< Graphics`Graphics`
<< Miscellaneous`Units`
<< Graphics`Legend`
<< Miscellaneous`PhysicalConstants`
th = 0.005;
SetOptions[{Plot, ListPlot, LogPlot, LogLogPlot, ParametricPlot},
  Frame → True, AspectRatio → 1 / GoldenRatio, PlotRange → All,
  PlotRegion → Automatic, Axes → True, AxesStyle → Automatic, GridLines → Automatic,
  PlotStyle → {{RGBColor[1, 0, 0], Thickness[th]}, {RGBColor[0, 1, 0], Thickness[th]},
    {RGBColor[0, 0, 1], Thickness[th]}, {RGBColor[0, 0, 0], Thickness[th]},
    {RGBColor[0, 0.8, 0.8], Thickness[th]}}, TextStyle → {FontSize → 14, FontWeight → "Bold"}];
DispOn = DisplayFunction → $DisplayFunction; DispOff = DisplayFunction → Identity;
```

Basics

■ SRIM tables

Muons in carbon from SRIM.

	m	in		out			
	105.66	p (MeV/c)		T (MeV)			
	0.1134 amu	29		3.98			
				p			
		4.4		30.493			
materials							
	material	range@10 srim cm	range@10 srim g/cm2	range/ rangeC	X0 cm	density g/cm3	
1	carbon	0.346	0.780	1.000	18.80	2.25300	
2	air	635	0.794	1.018	30420.00	0.00125	
3	aluminum	0.331	0.894	1.147	8.90	2.70200	
4	helium	4000	0.720	0.924	524000.00	0.00018	
5	hydrogen gas	366.4	0.329	0.423	73100.00	0.00090	
6	havar	0.12	0.996	1.278	1.67	8.30000	
7	kapton	0.528	0.755	0.969	28.60	1.43000	
8	mylar	0.531	0.742	0.952	28.70	1.39700	
9	polystyrene	0.644	0.683	0.876	42.40	1.06000	
10	silicon	0.373	0.866	1.111	9.36	2.32120	
11	sulfur	0.422	0.873	1.120	11.10	2.06860	
12	butane C4H10	243	0.629	0.807	17374.52	0.00259	

E (MeV)	dE/dex el	dE/dex nu	R(um)	long rms(u	lat rms (um)
1	4.49E-02	1.72E-05	54.93	2.89	4.04
1.1	4.16E-02	1.59E-05	65.08	3.38	4.77
1.2	3.88E-02	1.47E-05	76.01	3.88	5.55
1.3	3.64E-02	1.37E-05	87.7	4.39	6.38
1.4	3.43E-02	1.29E-05	100.13	4.92	7.26
1.5	3.24E-02	1.21E-05	113.31	5.46	8.19
1.6	3.08E-02	1.14E-05	127.21	6.02	9.18
1.7	2.93E-02	1.08E-05	141.85	6.59	10.21
1.8	2.80E-02	1.03E-05	157.19	7.18	11.28
2	2.57E-02	9.40E-06	189.99	9.01	13.58
2.25	2.33E-02	8.47E-06	234.87	11.61	16.72
2.5	2.14E-02	7.72E-06	284.02	14.15	20.14
2.75	1.98E-02	7.10E-06	337.34	16.72	23.84
3	1.85E-02	6.57E-06	394.76	19.32	27.8
3.25	1.73E-02	6.12E-06	456.2	21.97	32.04
3.5	1.63E-02	5.73E-06	521.61	24.7	36.53
3.75	1.54E-02	5.39E-06	590.92	27.48	41.28
4	1.46E-02	5.09E-06	664.07	30.34	46.28
4.5	1.33E-02	4.58E-06	821.56	39.47	57.01
5	1.22E-02	4.17E-06	993.81	48.34	68.69

R=54.672 T^1.8

T=0.108 R^0.555

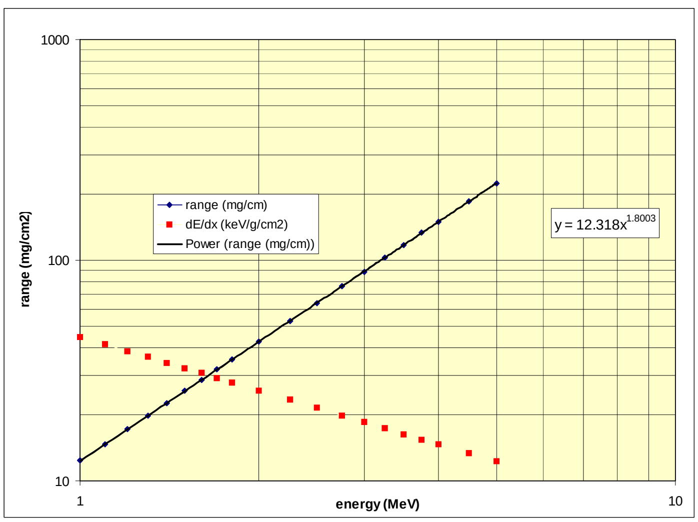


Fig: Carbon range and dE/dx for muons.

Muons in TPC from SRIM (density 0.9 mg/cm3)

See link.

Protons in TPC from SRIM

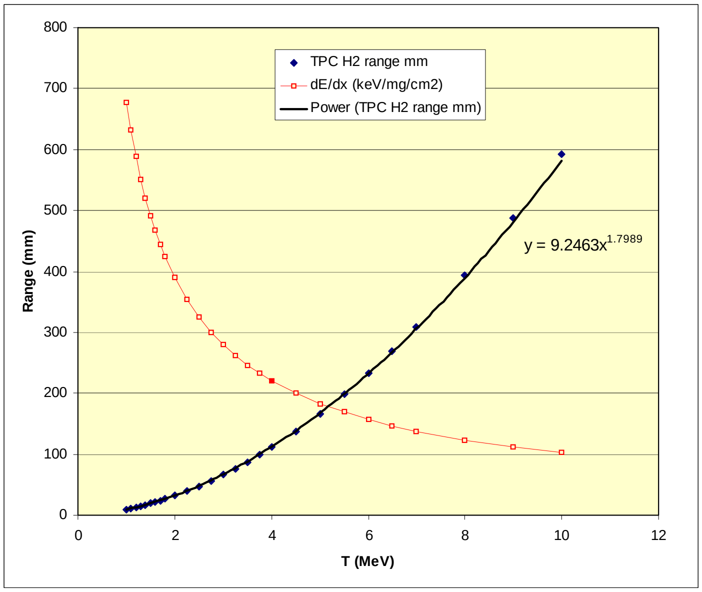


Fig: H2 range and dE/dx for protons.

■ Analytical approximations

Let's call the range r $\propto T^{1.8} \propto p^{3.6}$. From the SRIM range energy tables above we get

```
m = 105.66;
R[t_, k_] := k t^1.8
T[r_, k_] := (r/k)^(1/1.8)
k0 = 54.672 10^-1 2.253 ;
kCmu = k0 ;            (* muon r in mg/cm2 C as fct of EN in MeV *)
KCmu = k0 10^-2 / 1.06  ;     (* muon r in mm scint dens=1.06 as fct of EN in MeV *)
kHmu = k0 0.423  ;     (* muon r in mg/cm2 H as fct of EN in MeV *)
KHmu = k0 0.423 10 / 0.9 ;     (* muon  in mm TPC H as fct of EN in MeV *)
KHp = 9.25    ;          (* proton  in mm TPC H as fct of EN in MeV *)
KCp = KHp KCmu / KHmu;
Clear[r, k, t];
dEdxR1 = FullSimplify[D[T[r, k], r]]
dEdxT1 = FullSimplify[1. / D[R[t, k], t]]
dEdxR[r_, k_] := 0.55555555 / (k (r/k)^0.444444)
dEdxT[t_, k_] := 0.5555555555555556` / (k t^0.8`)
```

$$\frac{0.555556}{k\left(\frac{r}{k}\right)^{0.444444}}$$

$$\frac{0.555556}{k\, t^{0.8}}$$

```
t = 10; res = {R[t, kCmu] g / cm2, R[t, KCmu] mm, R[t, kHmu] g / cm2, R[t, KHmu] mm, R[t, KHp] mm, R[t, KCp] mm}
```

$$\left\{\frac{777.188\, g}{cm2},\ 7.33196\, mm,\ \frac{328.751\, g}{cm2},\ 3652.78\, mm,\ 583.636\, mm,\ 1.17149\, mm\right\}$$

Some consistency checks

```
R[t, KHmu] / R[t, KHp]
T[res[[4]] / mm, KHmu]
R[4, kHmu] g / cm2 / m 10^3
```

```
6.25867
```

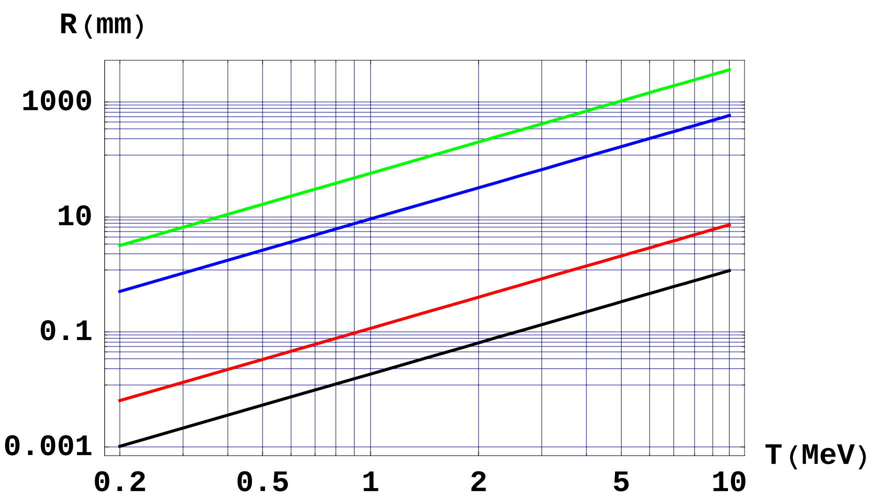
```
10.
```

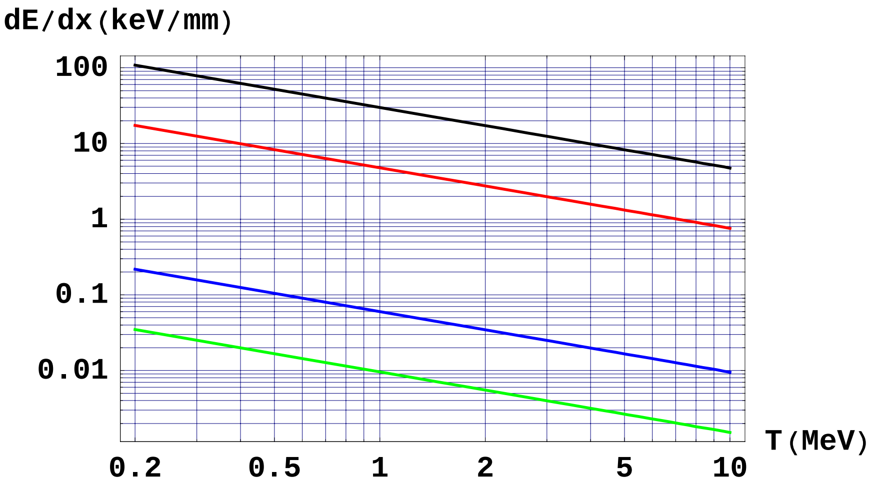
$\frac{597.949\,g}{cm2}$

```
dEdxT[1, KHp]
```

```
0.0600601
```

```
DispOn;
t = Table[i, {i, 0, 300, 4}];
(*Plot[{r[x,KCmu],r[x,KHmu],r[x,KHp]},{x,0.01,10},
   AxesLabel→{"T(MeV)", "R(mm)"},PlotLegend->{"Cmu","Hmu","Hp"}];*)
LogLogPlot[{R[x, KCmu], R[x, KHmu], R[x, KHp], R[x, KCp]}, {x, 0.2, 10}, AxesLabel → {"T(MeV)", "R(mm)"}];
LogLogPlot[{dEdxT[x, KCmu], dEdxT[x, KHmu], dEdxT[x, KHp], dEdxT[x, KCp]},
  {x, 0.2, 10}, AxesLabel → {"T(MeV)", "dE/dx(keV/mm)"}];
LogPlot[{dEdxR[x, KCmu], dEdxR[x, KHmu], dEdxR[x, KHp], dEdxR[x, KCp]},
  {x, 0.1, 300}, AxesLabel → {"R(mm)", "dE/dx(keV/mm)"},
  GridLines -> {t, Automatic}];
```





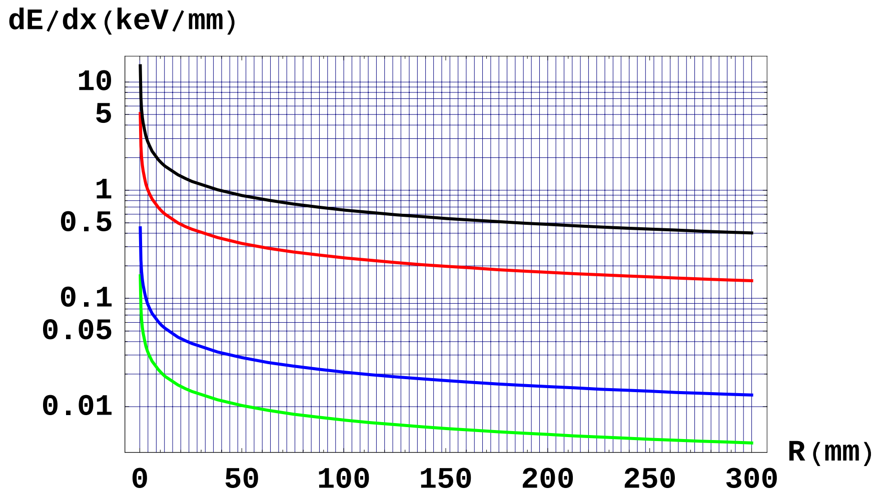


Fig: Range-Energy-dE/dx for Scint-mu red, H-mu green, H-p blue, Scint-p black

Calculations for TPC

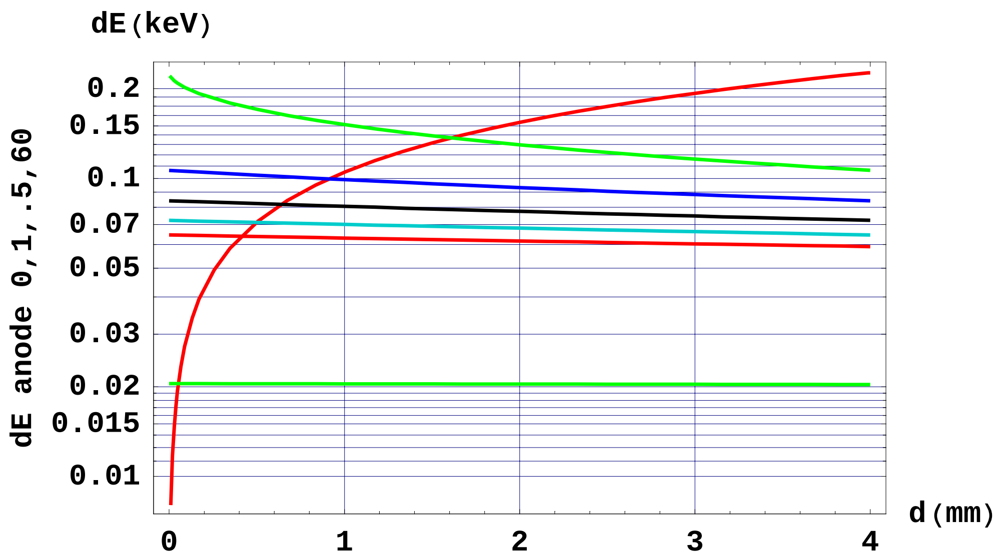
We can now define the energy deposited per anode if the muon stops at a distance d inside the last anode. Stop anode=0, first upstream=1 etc

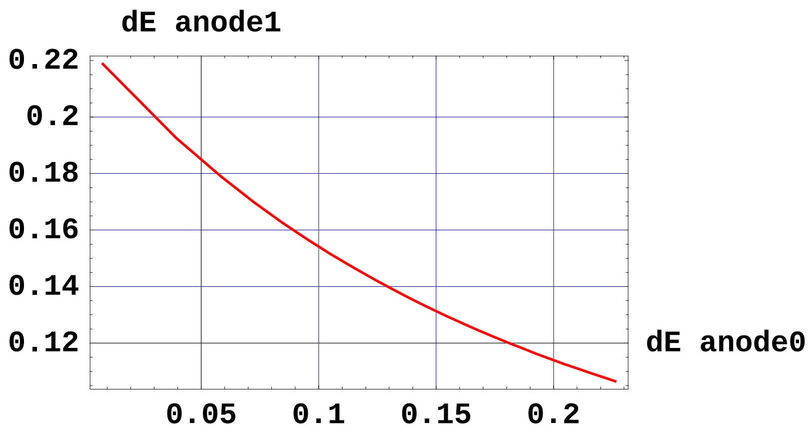
```
delT[d_, an_] := T[d + 4 an , KHmu] - If[an > 0, T[d + 4 (an - 1), KHmu], 0.]
Table[delT[0, i], {i, 0, 10}]
Table[delT[4, i], {i, 0, 10}]
```

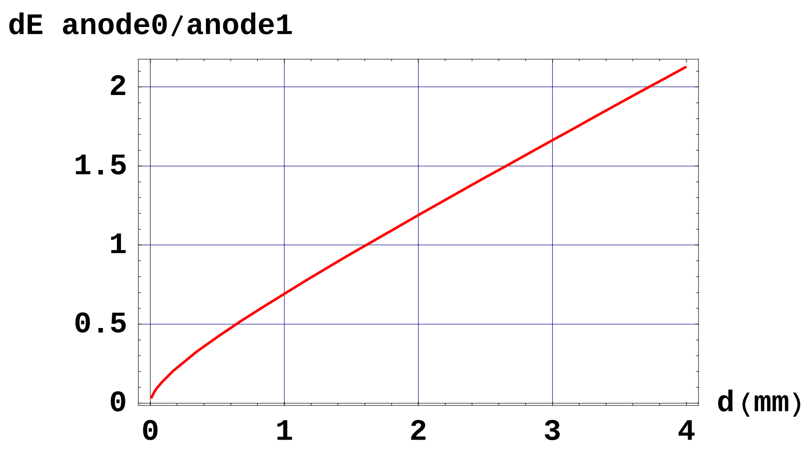
```
{0., 0.226591, 0.106437, 0.0841384, 0.0722965,
 0.0645995, 0.0590615, 0.0548214, 0.0514352, 0.048647, 0.0462972}
```

```
{0.226591, 0.106437, 0.0841384, 0.0722965, 0.0645995,
 0.0590615, 0.0548214, 0.0514352, 0.048647, 0.0462972, 0.0442806}
```

```
LogPlot[{delT[d, 0], delT[d, 1], delT[d, 2], delT[d, 3], delT[d, 4], delT[d, 5], delT[d, 60]},
  {d, 0.01, 3.99}, AxesLabel → {"d(mm)", "dE(keV)"}, FrameLabel → "dE anode 0,1,.5,60"];
ParametricPlot[{delT[d, 0], delT[d, 1]}, {d, 0.01, 3.99}, AxesLabel → {"dE anode0", "dE anode1"}];
Plot[{delT[d, 0] / delT[d, 1]}, {d, 0.01, 3.99}, AxesLabel → {"d(mm)", "dE anode0/anode1"}];
```



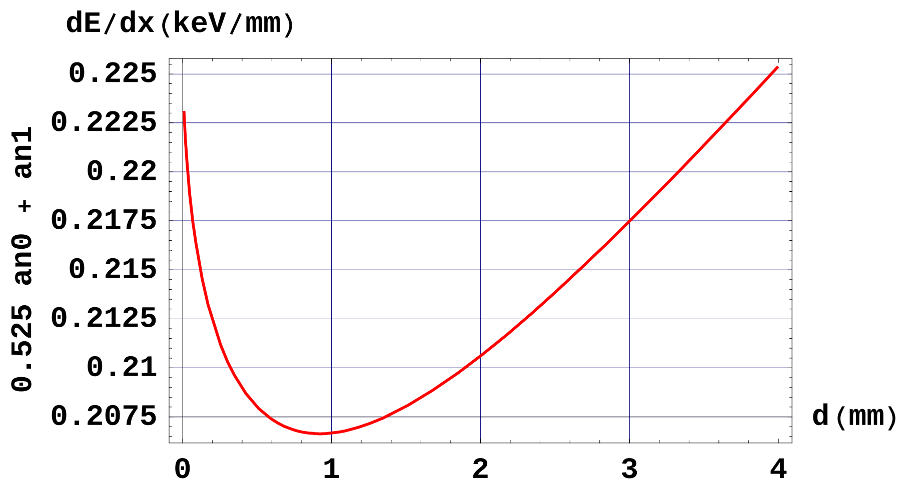




We can use an=0 plus an=1 information to define the muon stop signal. Or we can use it to determine the stop location.

```
0.12 / 0.22
Plot[{0.525 delT[d, 0] + delT[d, 1]}, {d, 0.01, 3.99},
  AxesLabel → {"d (mm)", "dE/dx (keV/mm)"}, FrameLabel → "0.525 an0 + an1 "];
```

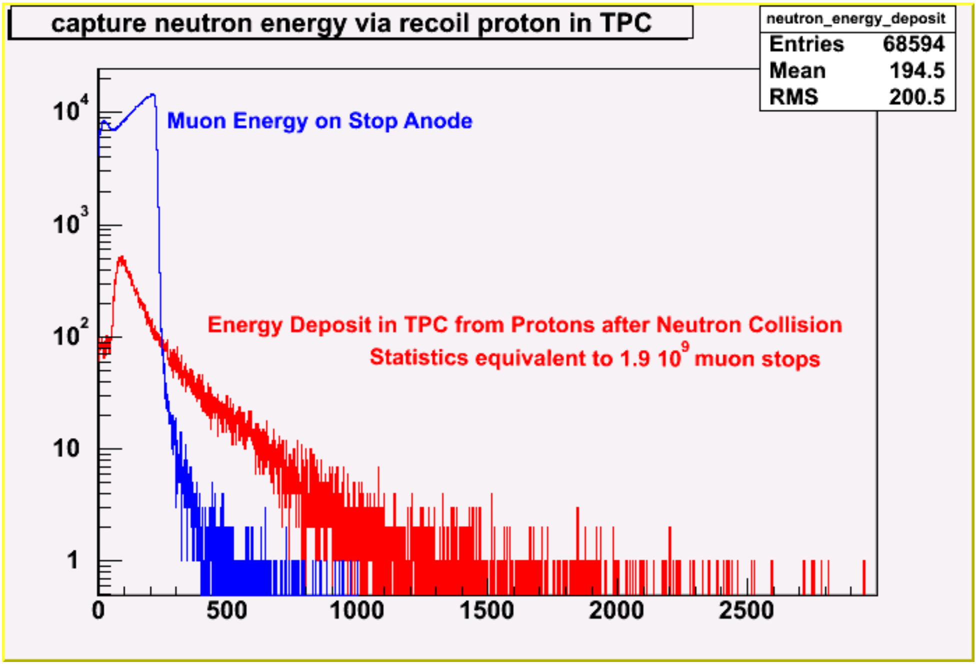
```
0.545455
```

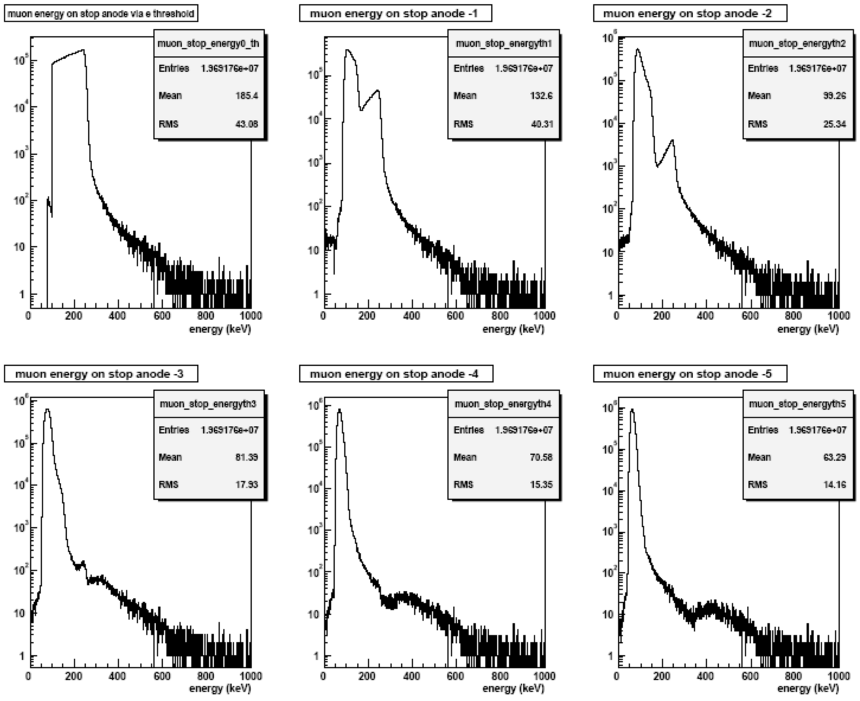



```
SetOptions[Plot];
```

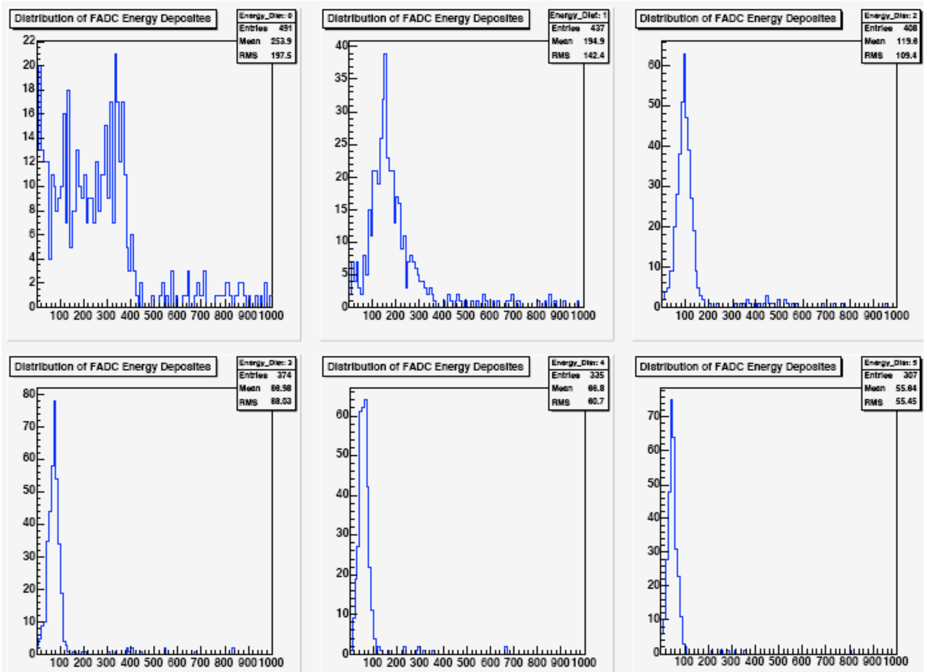
Comparison with data and MC

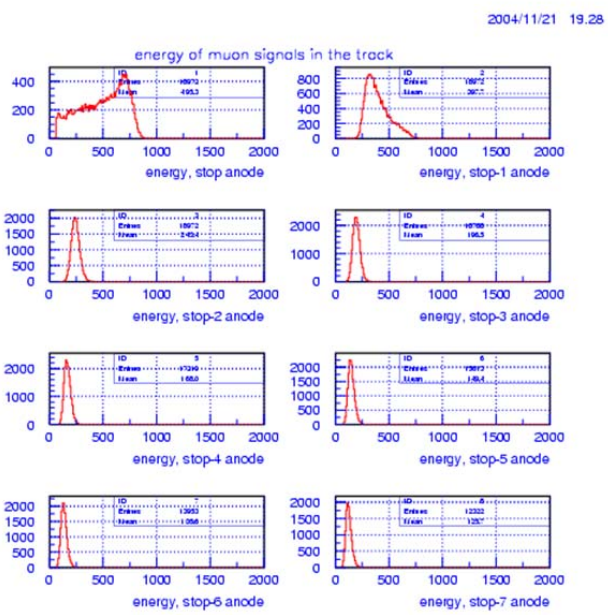
■ Bernard





■ FADC (Jordan, Fred, Oleg)





E stop ~ 0 -230 keV
E stop-1 ~ 100 - 200 keV
E stop-2 ~ 90 keV
E stop-3 ~ 72 keV
E stop-4 ~ 66 KeV
E stop-5 ~ 60 keV
E stop-6 ~ 54 keV
E stop-7 ~ 51 keV

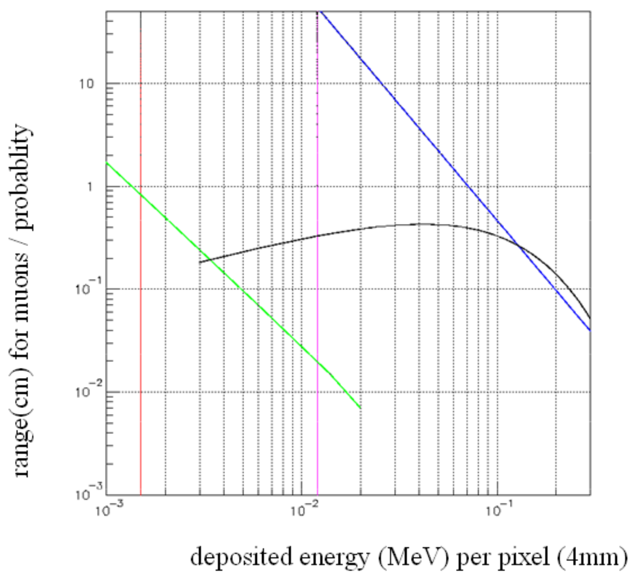
For runs:
TPC HV = 5kV,
Attenuation =6dB

From that :
for energy 1ch~0.4keV
for amplitude 1ch~3keV

■ Peter's old transparency

energy deposition in TPC

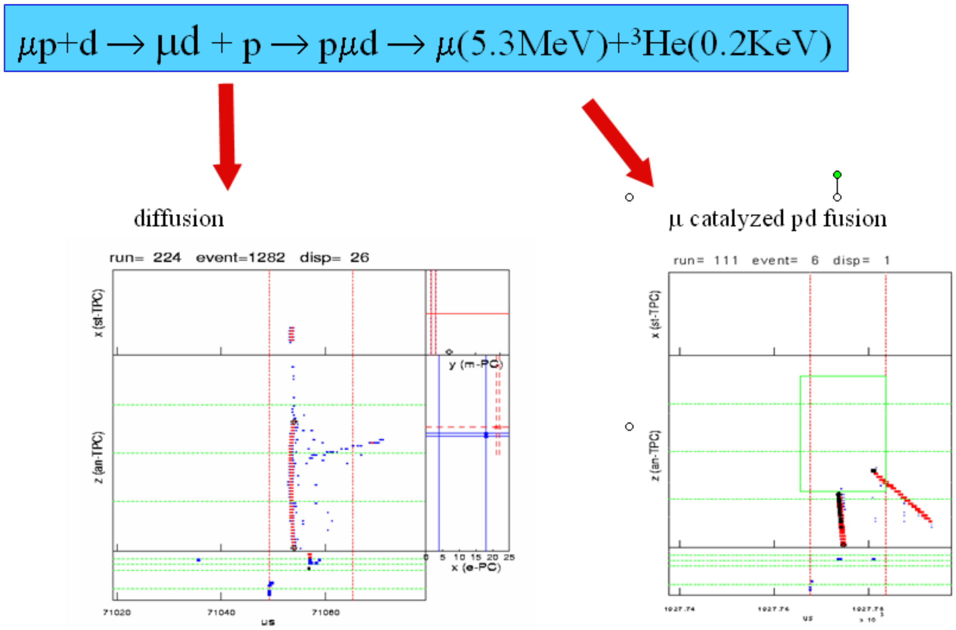
- **stopping μ's**
- **MIPs (electrons)**
- **δ electrons**
- **Alvarez muons**: $\mu p + d \longrightarrow p\mu d \longrightarrow \mu(5.5\text{MeV}) + {}^3\text{He}$
- **impurity capture** $\mu + Z \longrightarrow Z' + n + \nu$



Genna's baseline restorer

see link

Peter's discussion of Alvarez trigger



Conclusions

■ Energies and ranges

```
En = {{particle, "δE (keV)", "range TPC(mm)"},
   {"MIPS", "~1.5" , ∞}, {"mu 60 anodes before stop", delT[2, 60] 1000, 120},
   {"mu stop max signal", delT[4, 0] 1000, 0}, {Alvarez, dEdxT[5.4, KHmu] 4 1000, R[5.4, KHmu]},
   {"5.2 MeV p in TPC", dEdxT[5.2, KHp] 4 1000, R[5.2, KHp]},
   {"4 MeV p in TPC", dEdxT[4, KHp] 4 1000, R[4, KHp]}, {"1.5 MeV p in TPC",
    dEdxT[1.5, KHp] 4 1000, R[1.5, KHp]}, {"1 MeV p in TPC", dEdxT[1, KHp] 4 1000, R[1, KHp]}};
TableForm[
 En]
```

particle	δE (keV)	range TPC(mm)
MIPS	~1.5	∞
mu 60 anodes before stop	20.4025	120
mu stop max signal	226.591	0
Alvarez	9.95975	1204.85
5.2 MeV p in TPC	64.2456	179.865
4 MeV p in TPC	79.2497	112.163
1.5 MeV p in TPC	173.689	19.1914
1 MeV p in TPC	240.24	9.25

Comments: For mu stop max signal the deviation of the range-energy relation from a simple power law becomes significant. The exact SRIM value is δE=237 KeV.

■ Issues

i) threshold settings for run9 (no big change to run 8). We should have
EL above noise
EH best compromise for systematics in muon stop definition
EVH slightly above muon stop anode, but it misses 3He.
In case we have a chance to see Alvarez we might want to reduce EVH to 150keV, to see 3He as an isolated pixel.
Impact on mu stop definition and increase capture background should be discussed.
Threshold verification is important.

ii) Full FADC readout of mu stops would allow ~1mm mustop definition via δE(0) 0.525 /δE(1), where (0=stop anode and 1=one before). Probably unrealistic for all muons, but perhaps helpful for diffusion/capture searches.
The combination δE(0) 0.525 + δE(1) leads to a well defined peak of ~230 keV in the muon stopping energy.

iii) EVH seems ok for the capture skimming path. But 3He has energy 0.2 MeV, so Alvarez candidates will be missed. Skimming for isolated EVH pixel will probably lead to too much polution.

iv) Recoil protons as calculated by Bernhard are interesting. The low energy guys <1.5 MeV might be mixed with diffused capture events. For Ep>4 MeV one might achieve a full kinematic reconstruction (timing via punch through upper/lower TPC plane). They are pretty distinct.