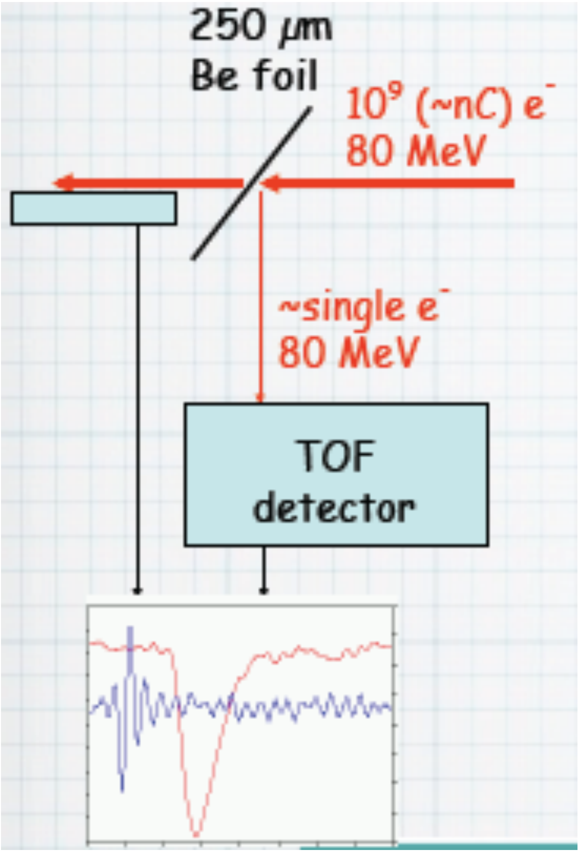
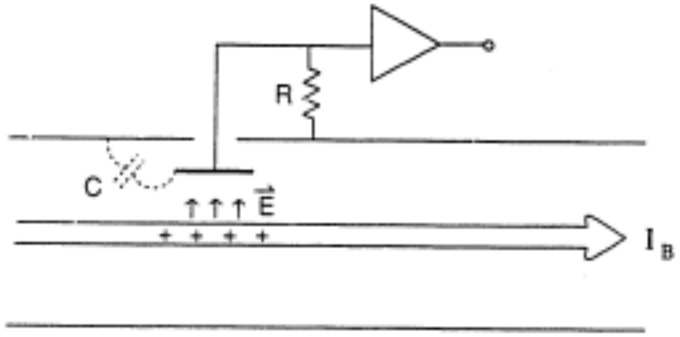
The single electron project

S.White, BNL Physics

Oct. 6, ATF User's Meeting



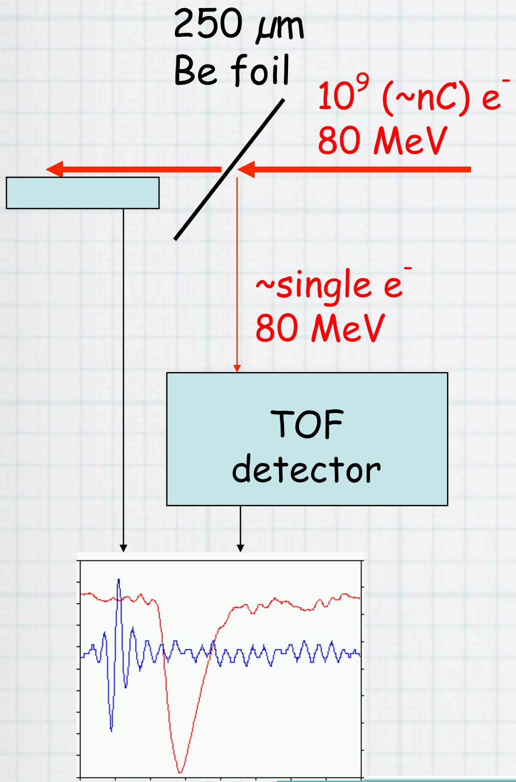


- a unique feature of ATF beam is 3 picosec bunch length (streak camera)
- could this be exploited to evaluate fast timing detectors?
- We present a method to produce a compact secondary beam.
- ~1 electron/pulse
- Initial use to develop fast timing detectors

representing work of:
V.Yakimenko, M.Fedurin, T.Tsang, M.Chiu, M.Diwan,
G.Atoian(BNL)
K.McDonald(Princeton)

correspondents:
H.Frisch, J.Va'vra, K.Goulianos, D.Acker, I.Mousienko,
P.Vaska, M.Suyama

Why is a 100 MeV, single electron, 3 picosecond beam interesting?

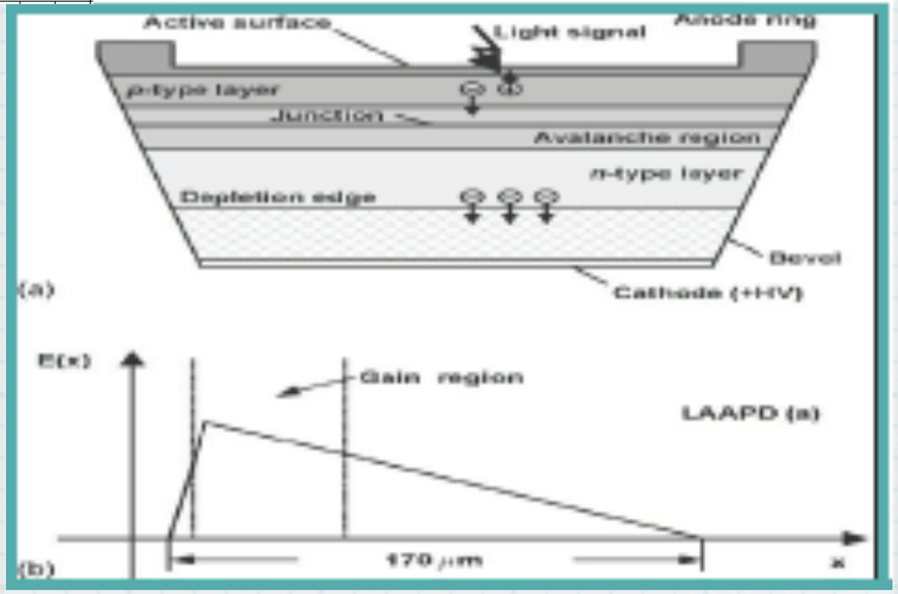


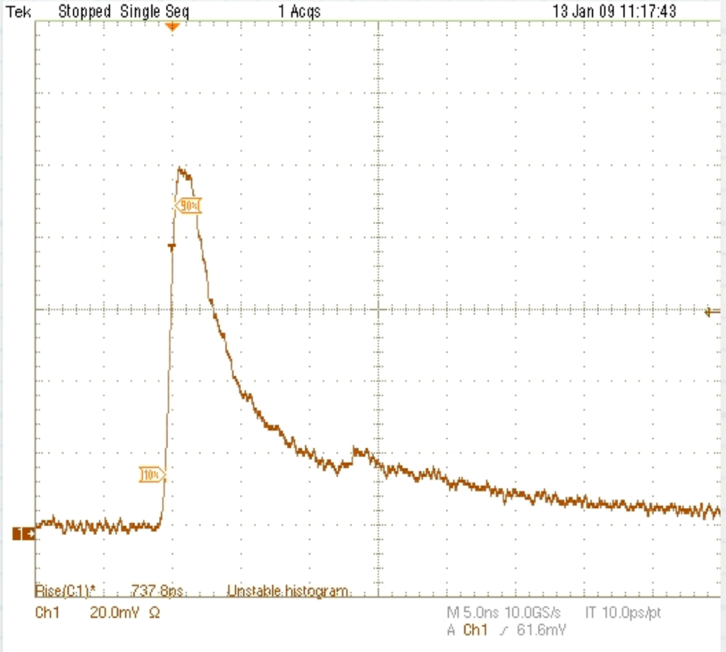
250 μm
Be foil

10^9 (~nC) e^-
80 MeV

~single e^-
80 MeV

TOF
detector





Deep diffused avalanche photodiode

650 picosecond risetime (β's)

"A 10 picosecond time of flight detector using APD's", SNW et al.

100 years of subatomic Structure

- Rutherford, Geiger, Marsden (1909)
  - Atom's 100th Birthday!
  - Rutherford's teacher, JJ Thomson, discovered electron 10 years earlier
- "counter experiment"
  - Beam of 5 MegaVolt α particles from Radium C decay
- Use Rutherford scattering for a "1 step" secondary beam

JJ Thomson & Ernest Rutherford

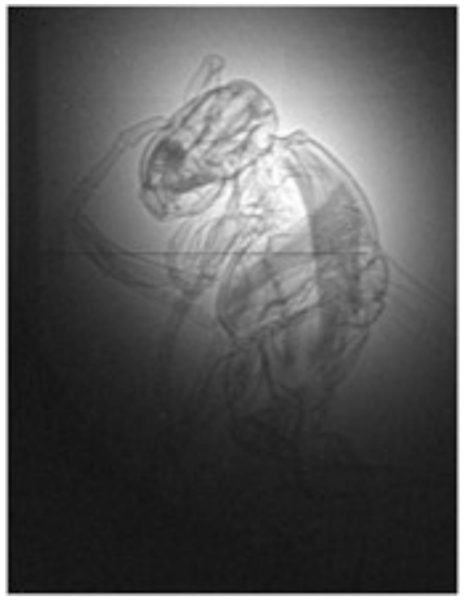
Question: with an incident beam of 10^9 60-80 MeV electrons, a ~1 mm target (Al or Be), how many are scattered @90 degrees into a ~1cm^2 detector 30 cm away?

Answer: ~1 !

- calculations presented in:"LBNE energy calibration using a 100 MeV electron accelerator"-SNW& Vitaly Yakimenko http://arxiv.org/abs/1004.3068
- small accelerators previously used for calibration. ie:
- **Super K made good use of a 5-16 MeV medical accelerator -Mitsubishi ML-15MIII. They used a conventional secondary beam design (requires space)**

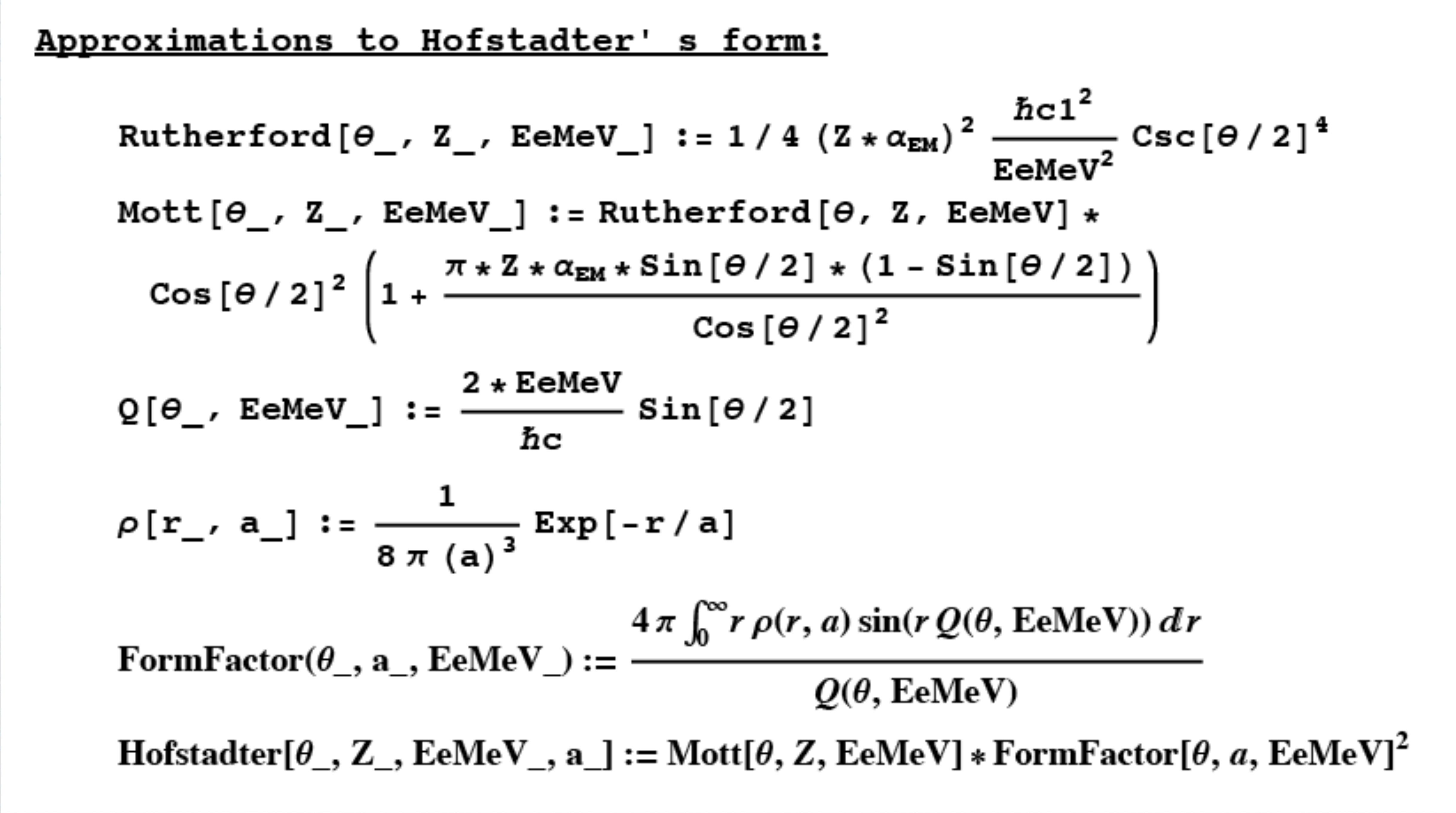
Background issues

- It would be almost impossible to calculate, from first principles, detector backgrounds from scraping, etc to the level of ~1 counts/pulse
- Vitaly’s intuition was that such backgrounds are low at ATF
- the bee:



- Our approach has been to focus entirely on APD based devices. This makes it easy to analyze backgrounds since rates and energy deposition depend primarily on area and effective depth.

Wide angle electron scattering



Approximations to Hofstadter' s form:

$$\text{Rutherford}[\theta\_,\ Z\_,\ \text{EeMeV}\_] := 1/4\ (Z * \alpha_{EM})^2\ \frac{\hbar c1^2}{\text{EeMeV}^2}\ \text{Csc}[\theta/2]^4$$

$$\text{Mott}[\theta\_,\ Z\_,\ \text{EeMeV}\_] := \text{Rutherford}[\theta,\ Z,\ \text{EeMeV}] * \text{Cos}[\theta/2]^2 \left(1 + \frac{\pi * Z * \alpha_{EM} * \text{Sin}[\theta/2] * (1 - \text{Sin}[\theta/2])}{\text{Cos}[\theta/2]^2}\right)$$

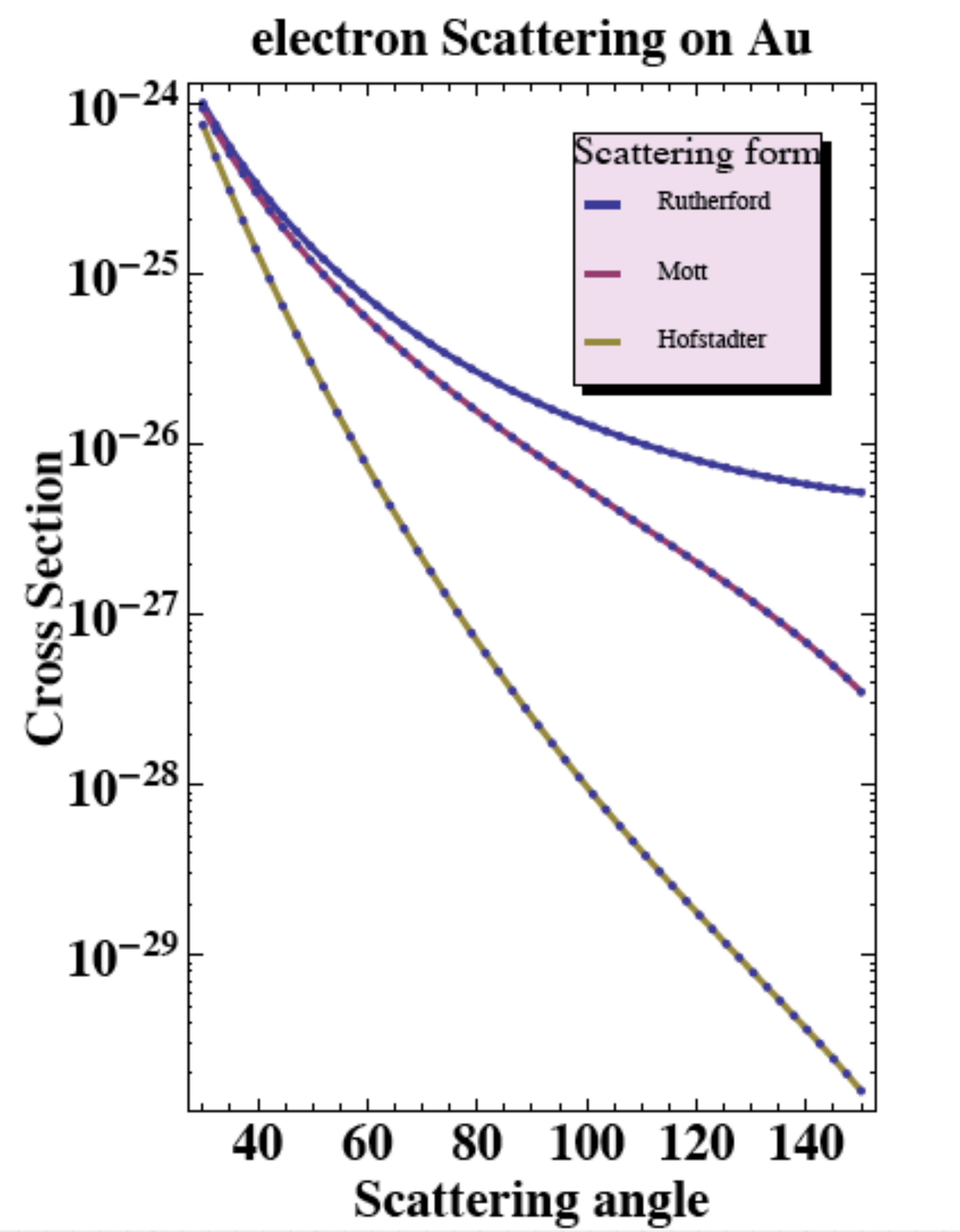
$$Q[\theta\_,\ \text{EeMeV}\_] := \frac{2 * \text{EeMeV}}{\hbar c}\ \text{Sin}[\theta/2]$$

$$\rho[r\_,\ a\_] := \frac{1}{8\pi\ (a)^3}\ \text{Exp}[-r/a]$$

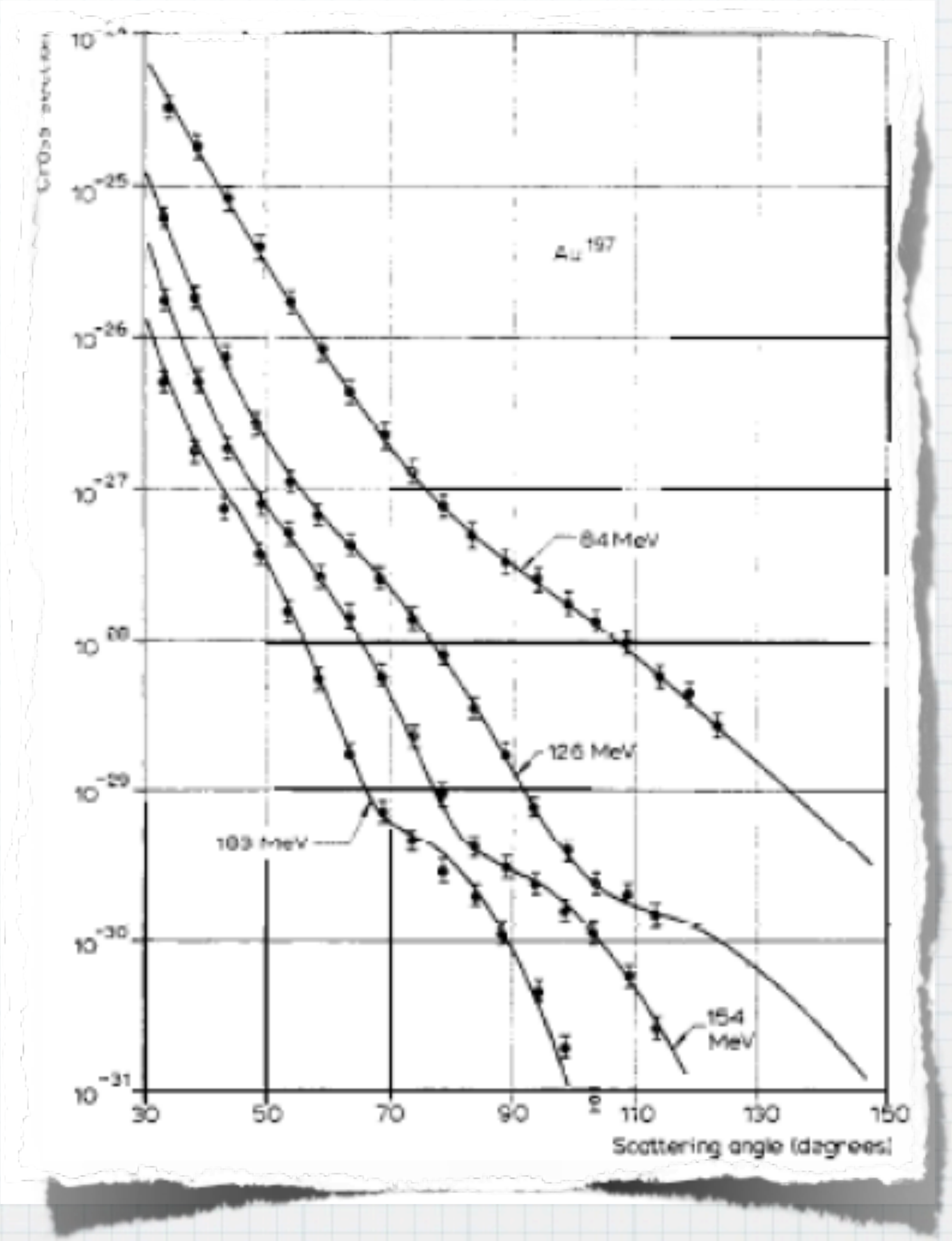
$$\text{FormFactor}(\theta\_,\ a\_,\ \text{EeMeV}\_) := \frac{4\pi \int_0^\infty r\,\rho(r, a)\sin(r\,Q(\theta, \text{EeMeV}))\,dr}{Q(\theta, \text{EeMeV})}$$

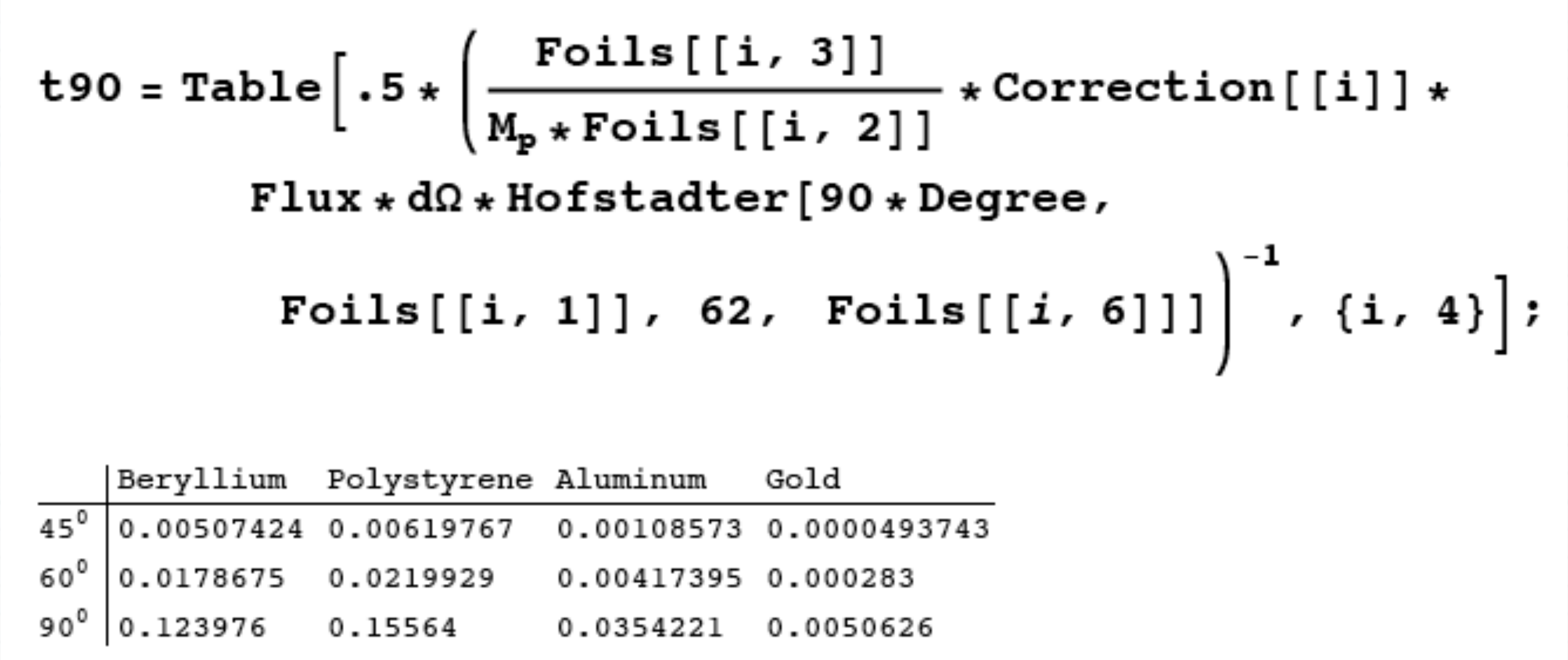
$$\text{Hofstadter}[\theta\_,\ Z\_,\ \text{EeMeV}\_,\ a\_] := \text{Mott}[\theta, Z, \text{EeMeV}] * \text{FormFactor}[\theta, a, \text{EeMeV}]^2$$

this calculation



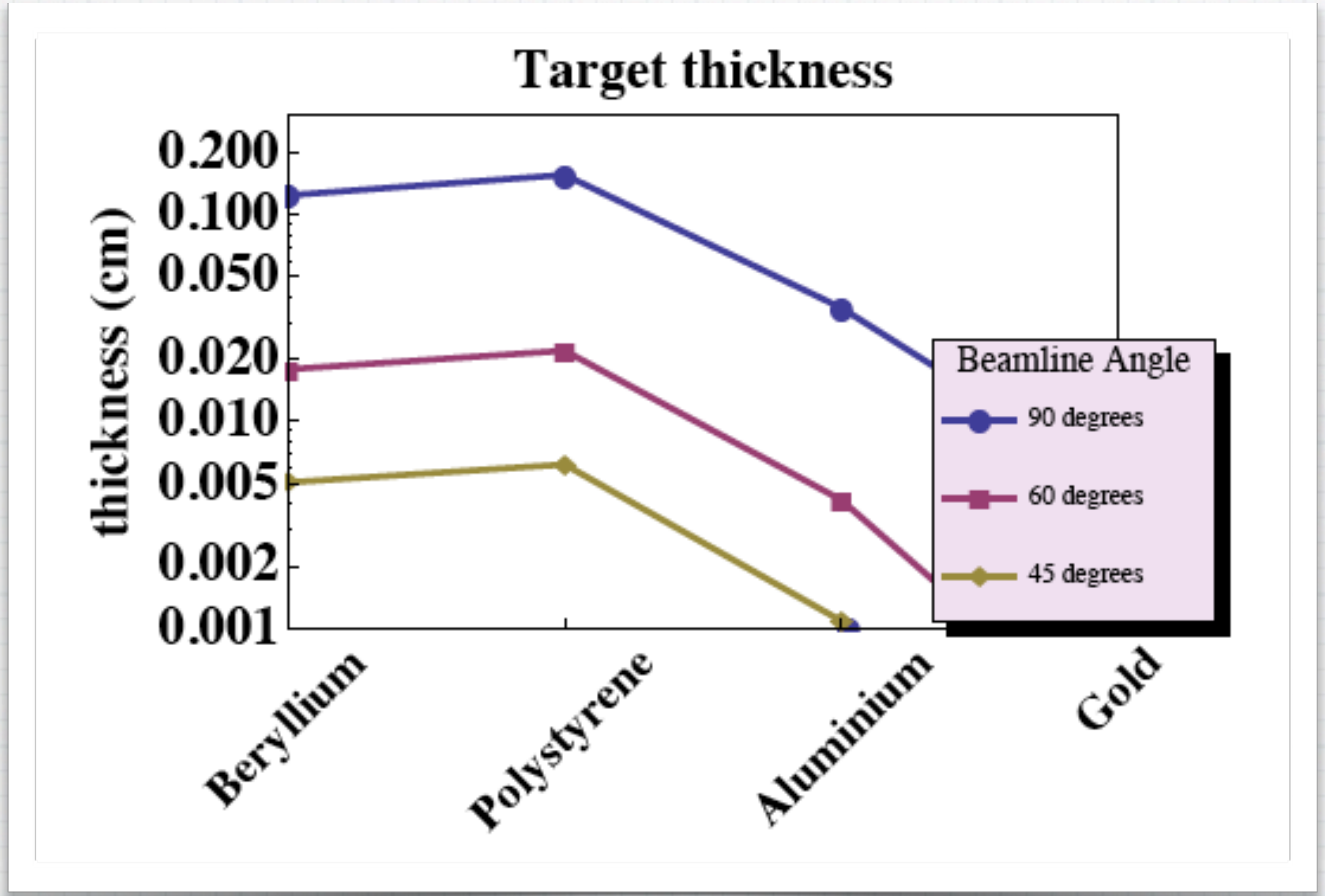
Hofstadter



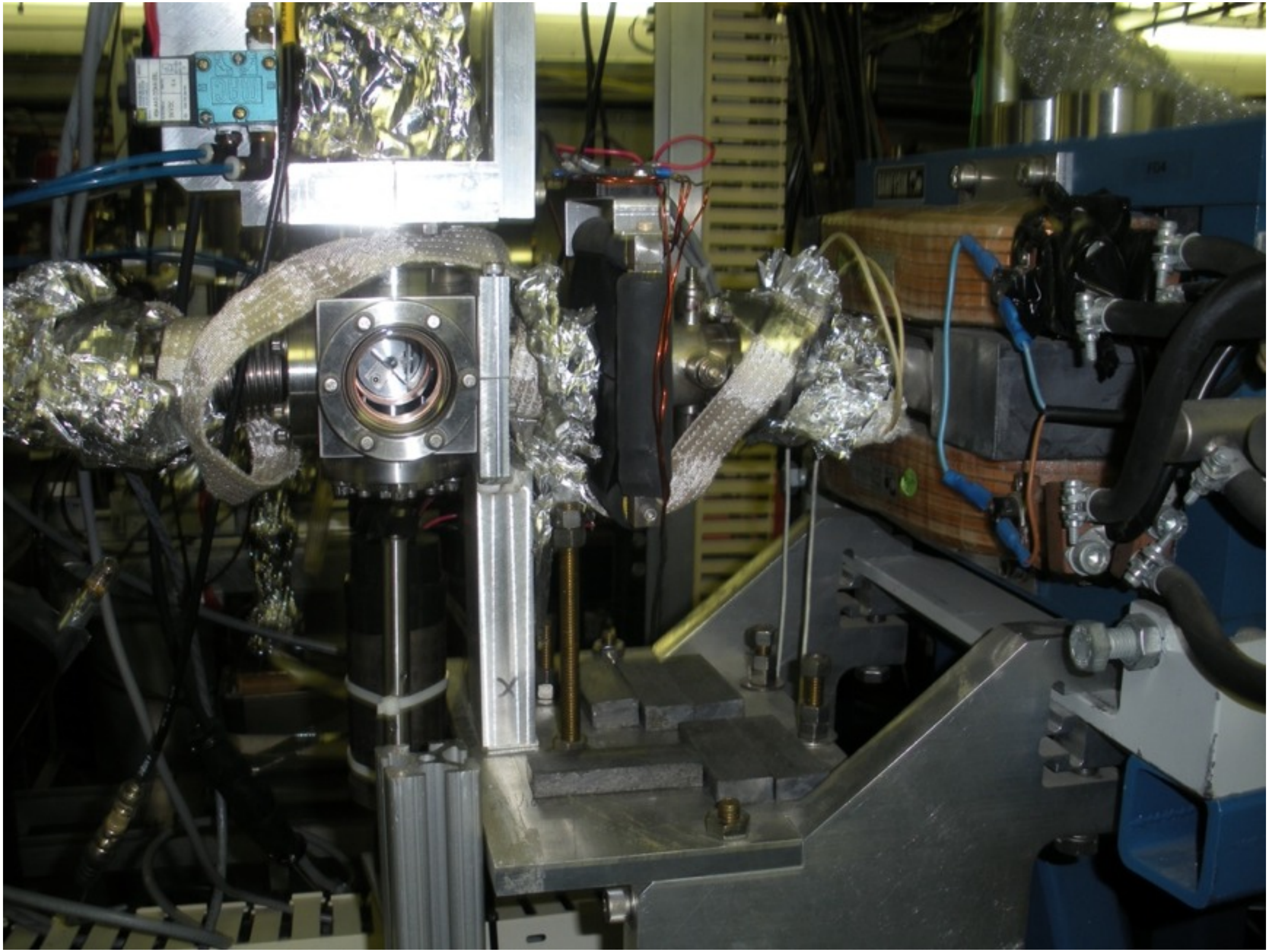


```
t90 = Table[.5 * (Foils[[i, 3]] / (Mp * Foils[[i, 2]]) * Correction[[i]] *
        Flux * dΩ * Hofstadter[90 * Degree,
          Foils[[i, 1]], 62, Foils[[i, 6]]])^-1, {i, 4}];
```

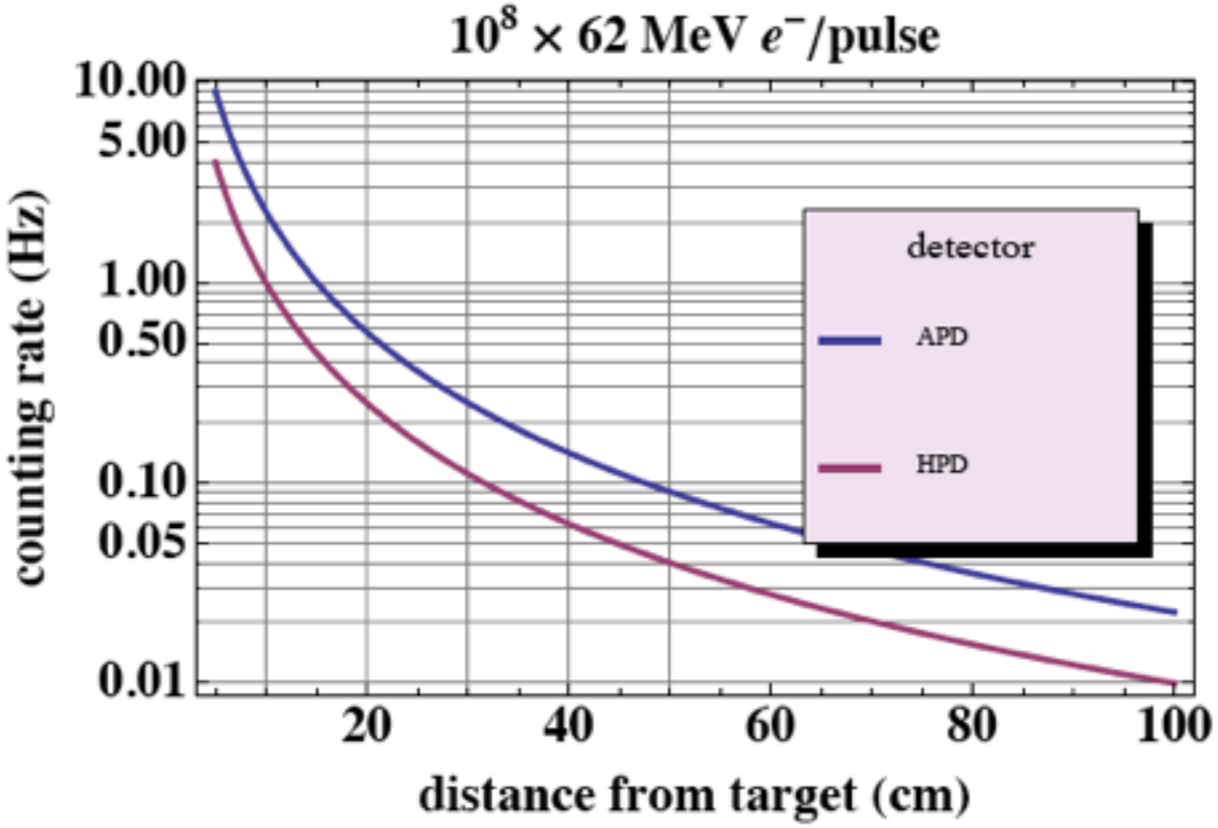
	Beryllium	Polystyrene	Aluminum	Gold
45^0	0.00507424	0.00619767	0.00108573	0.0000493743
60^0	0.0178675	0.0219929	0.00417395	0.000283
90^0	0.123976	0.15564	0.0354221	0.0050626

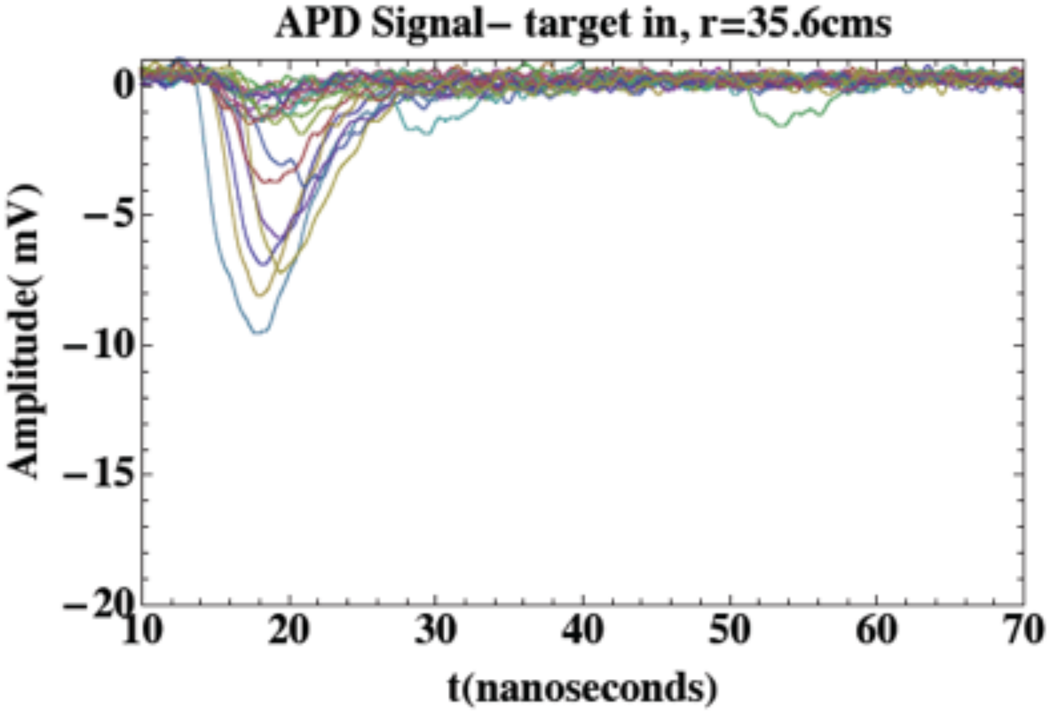


the beamline

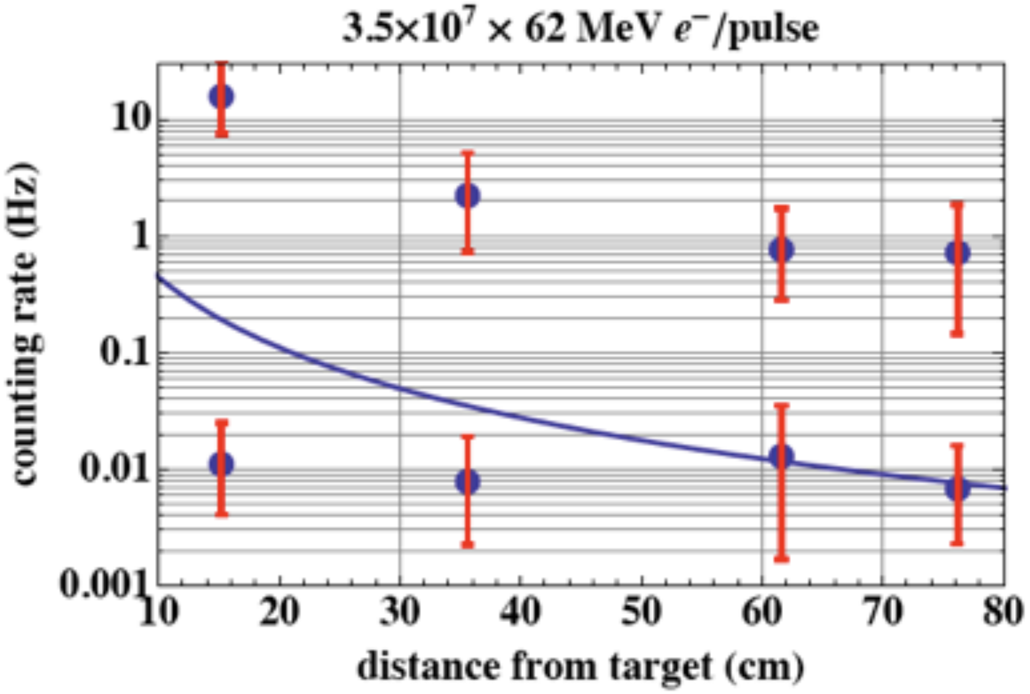


Initial tests (Al)

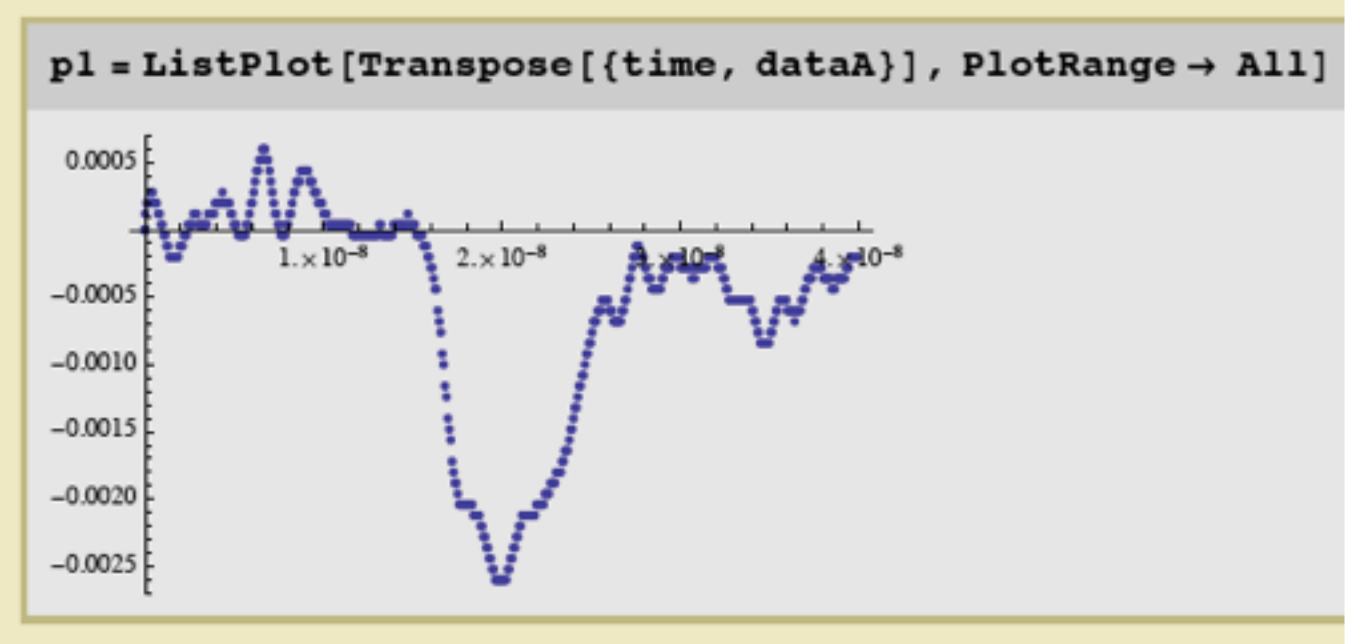

$10^8 \times 62$ MeV e^-/pulse


APD Signal– target in, r=35.6cms

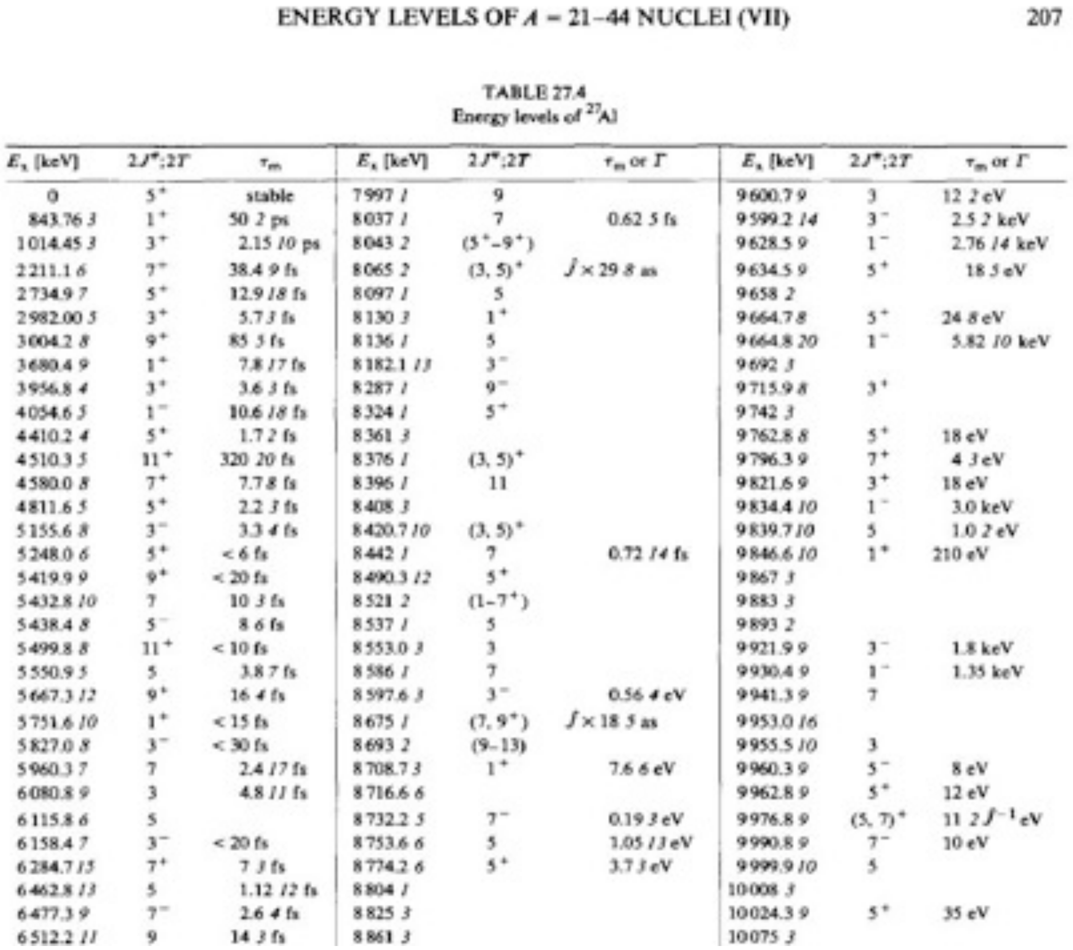
- “target out” background well below scattered rate
- “target in” rate ~10* calculation
- signal has v=c
- 1 X0 not effective
- concluded few MeV gamma


$3.5\times10^7 \times 62$ MeV e^-/pulse

Al is very messy!



```
p1 = ListPlot[Transpose[{time, dataA}], PlotRange → All]
```



ENERGY LEVELS OF *A* = 21–44 NUCLEI (VII) 207

TABLE 27.4
Energy levels of ^{27}Al

E_x [keV]	$2J^\pi;2T$	τ_m	E_x [keV]	$2J^\pi;2T$	τ_m or Γ	E_x [keV]	$2J^\pi;2T$	τ_m or Γ
0	5^+	stable	7997 *1*	9		9600.7 *9*	3	12 *2* eV
843.76 *3*	1^+	50 *2* ps	8037 *1*	7	0.62 *5* fs	9599.2 *14*	3^-	2.5 *2* keV
1014.45 *3*	3^+	2.15 *10* ps	8043 *2*	$(5^+–9^+)$		9628.5 *9*	1^-	2.76 *14* keV
2211.1 *6*	7^+	38.4 *9* fs	8065 *2*	$(3, 5)^+$	$\mathcal{J}$ × 29 *8* as	9634.5 *9*	5^+	18 *5* eV
2734.9 *7*	5^+	12.9 *18* fs	8097 *1*	5		9658 *2*		
2982.00 *5*	3^+	5.7 *3* fs	8130 *3*	1^+		9664.7 *8*	5^+	24 *8* eV
3004.2 *8*	9^+	85 *5* fs	8136 *1*	5		9664.8 *20*	1^-	5.82 *10* keV
3680.4 *9*	1^+	7.8 *17* fs	8182.1 *13*	3^-		9692 *3*		
3956.8 *4*	3^+	3.6 *3* fs	8287 *1*	9^-		9715.9 *8*	3^+	
4054.6 *5*	1^-	10.6 *18* fs	8324 *1*	5^+		9742 *3*		
4410.2 *4*	5^+	1.7 *2* fs	8361 *3*			9762.8 *8*	5^+	18 eV
4510.3 *5*	11^+	320 *20* fs	8376 *1*	$(3, 5)^+$		9796.3 *9*	7^+	4 *3* eV
4580.0 *8*	7^+	7.7 *8* fs	8396 *1*	11		9821.6 *9*	3^+	18 eV
4811.6 *5*	5^+	2.2 *3* fs	8408 *3*			9834.4 *10*	1^-	3.0 keV
5155.6 *8*	3^-	3.3 *4* fs	8420.7 *10*	$(3, 5)^+$		9839.7 *10*	5	1.0 *2* eV
5248.0 *6*	5^+	< 6 fs	8442 *1*	7	0.72 *14* fs	9846.6 *10*	1^+	210 eV
5419.9 *9*	9^+	< 20 fs	8490.3 *12*	5^+		9867 *3*		
5432.8 *10*	7	10 *3* fs	8521 *2*	$(1–7^+)$		9883 *3*		
5438.4 *8*	5^-	8 *6* fs	8537 *1*	5		9893 *2*		
5499.8 *8*	11^+	< 10 fs	8553.0 *3*	3		9921.9 *9*	3^-	1.8 keV
5550.9 *5*	5	3.8 *7* fs	8586 *1*	7		9930.4 *9*	1^-	1.35 keV
5667.3 *12*	9^+	16 *4* fs	8597.6 *3*	3^-	0.56 *4* eV	9941.3 *9*	7	
5751.6 *10*	1^+	< 15 fs	8675 *1*	$(7, 9^+)$	$\mathcal{J}$ × 18 *5* as	9953.0 *16*		
5827.0 *8*	3^-	< 30 fs	8693 *2*	(9–13)		9955.5 *10*	3	
5960.3 *7*	7	2.4 *17* fs	8708.7 *3*	1^+	7.6 *6* eV	9960.3 *9*	5^-	8 eV
6080.8 *9*	3	4.8 *11* fs	8716.6 *6*			9962.8 *9*	5^+	12 eV
6115.8 *6*	5		8732.2 *5*	7^-	0.19 *3* eV	9976.8 *9*	$(5, 7)^+$	11 *2* $\mathcal{J}^{-1}$ eV
6158.4 *7*	3^-	< 20 fs	8753.6 *6*	5	1.05 *13* eV	9990.8 *9*	7^-	10 eV
6284.7 *15*	7^+	7 *3* fs	8774.2 *6*	5^+	3.7 *3* eV	9999.9 *10*	5	
6462.8 *13*	5	1.12 *12* fs	8804 *1*			10008 *3*		
6477.3 *9*	7^-	2.6 *4* fs	8825 *3*			10024.3 *9*	5^+	35 eV
6512.2 *11*	9	14 *3* fs	8861 *3*			10075 *3*		

Beryllium is excellent!

we now have a backlog of high quality data, with different timing detectors, absorbers and distance to target. Requires ~1 week analysis to make suitable for publication.

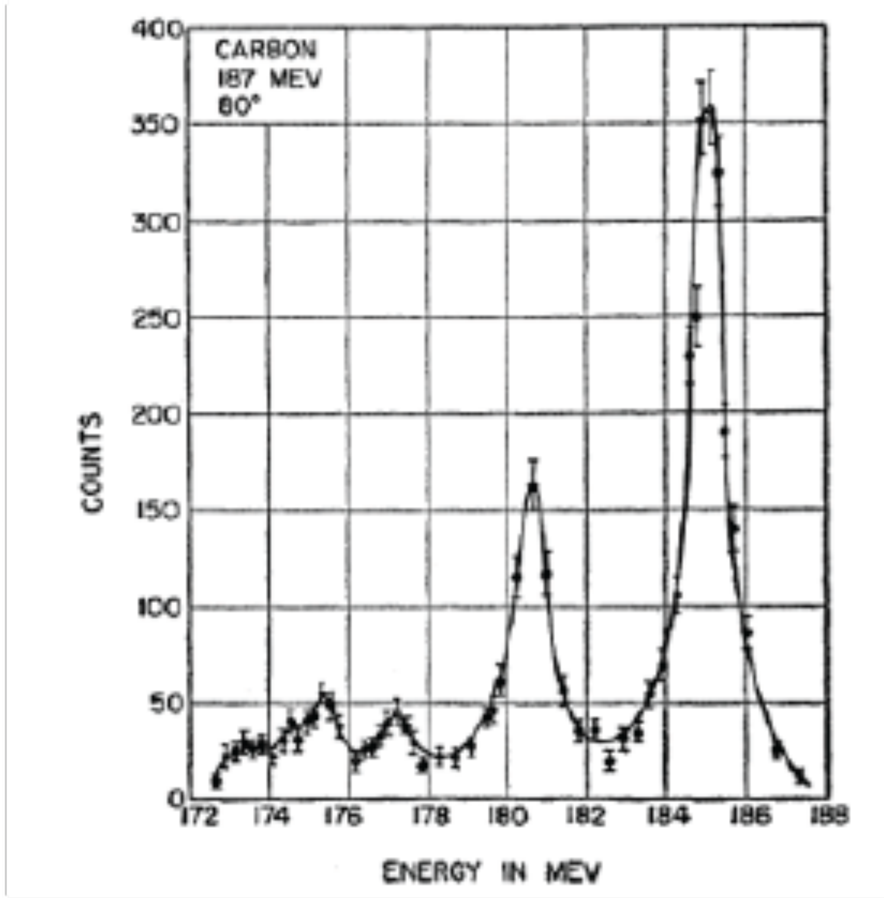
- In next talk we request:3 days beam studies, 10 days detector R&D beam time

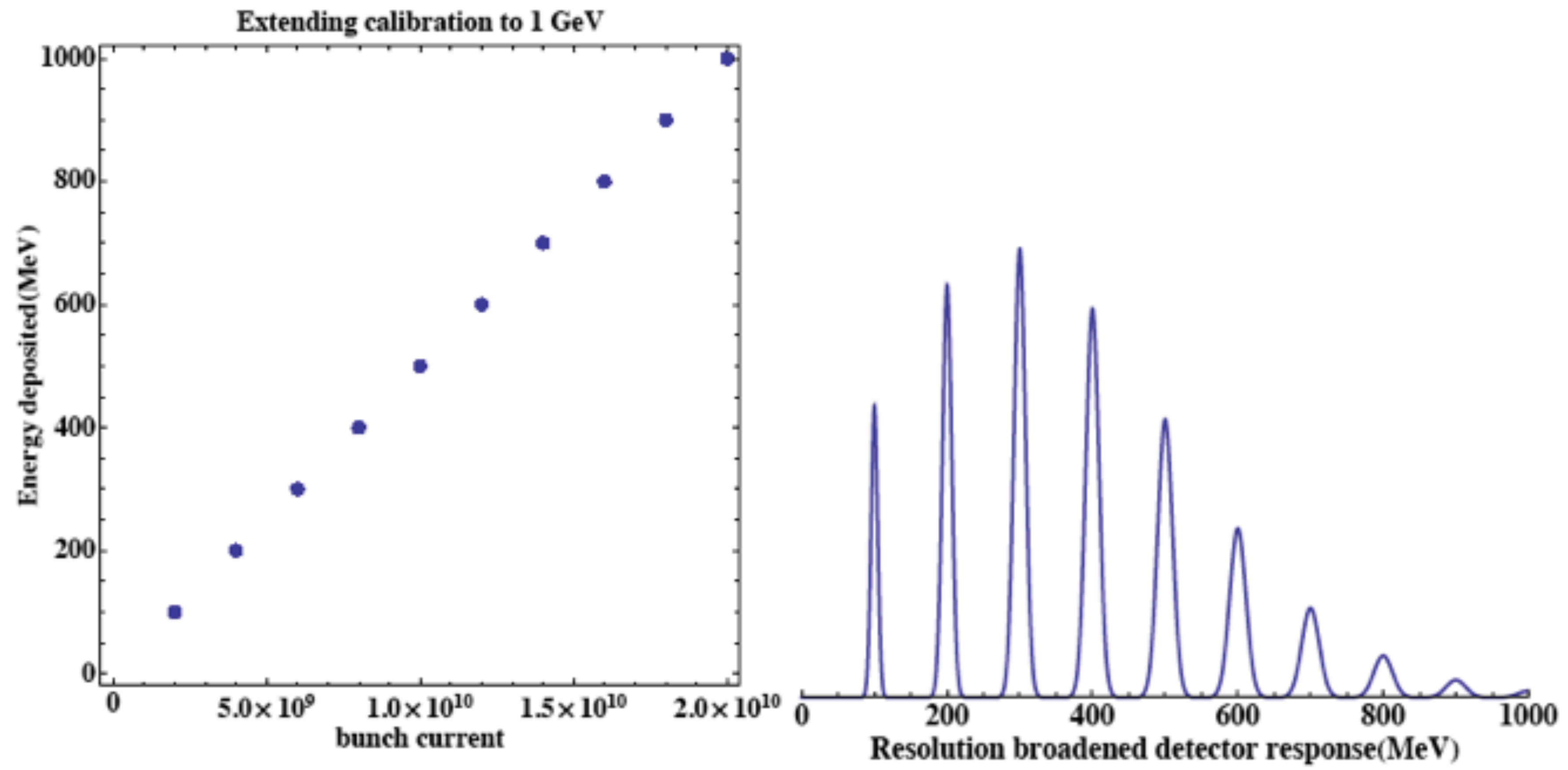
Our collaboration will provide:

- complete characterization of secondary beam (optimize “target out” background rates)
- currently data quality depend on resident ATF accelerator expertise in beam tuning-> codify procedure for beam setup
- “oscilloscope-based” data acquisition system initially slow and best understood scope was 500 MHz one
- ->make permanent installation based on ~$1000, 4-channel scope on a chip (DRS4 evaluated by us on loan from Frisch). Also higher performance chips in development (u.Chicago,Hawaii, Orsay,Saclay)- we will provide this.
- high daq rate and fast online feedback

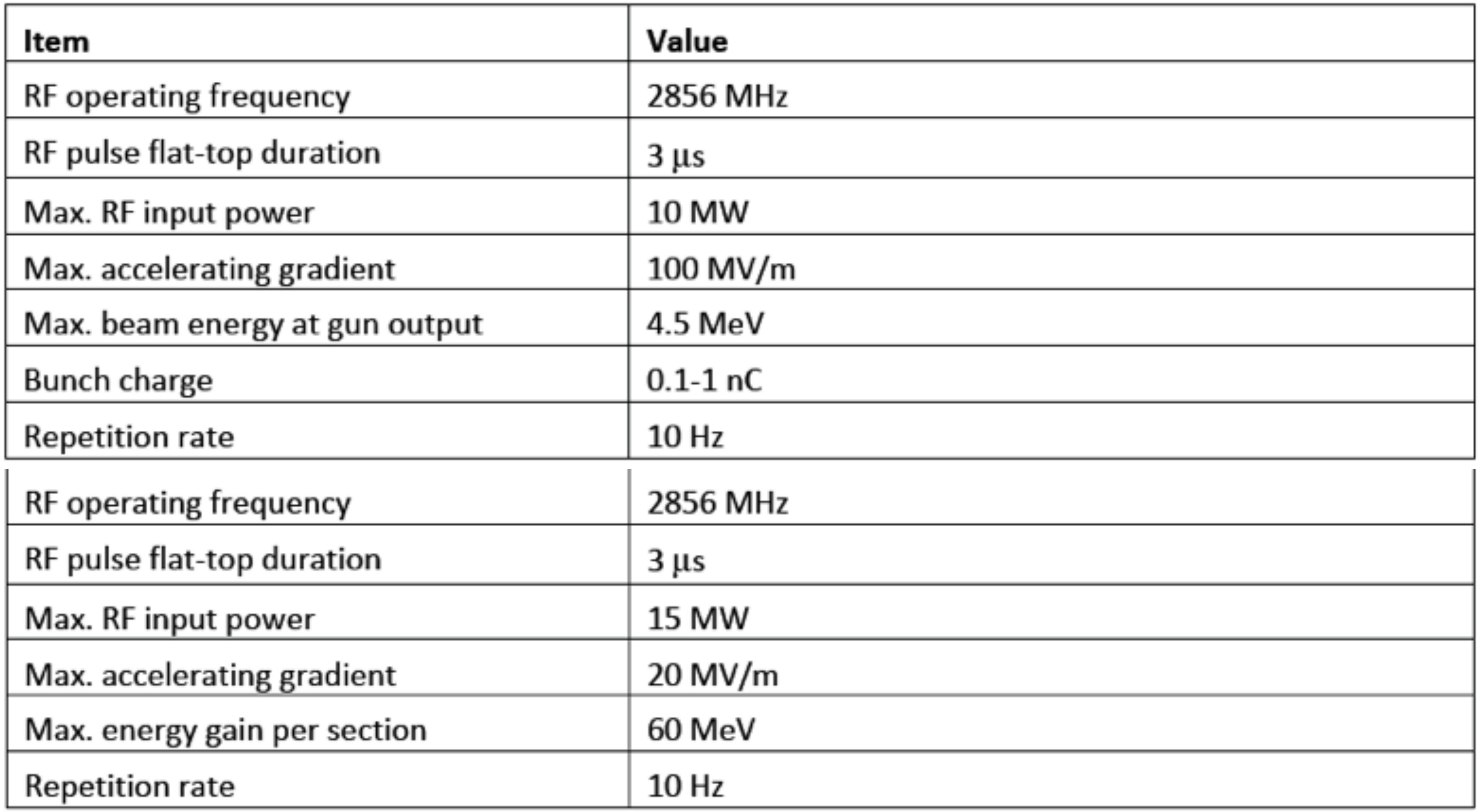
Addendum (slides related to a proposal for use of this design in an accelerator to calibrate LBNE)

Interesting features for calibration



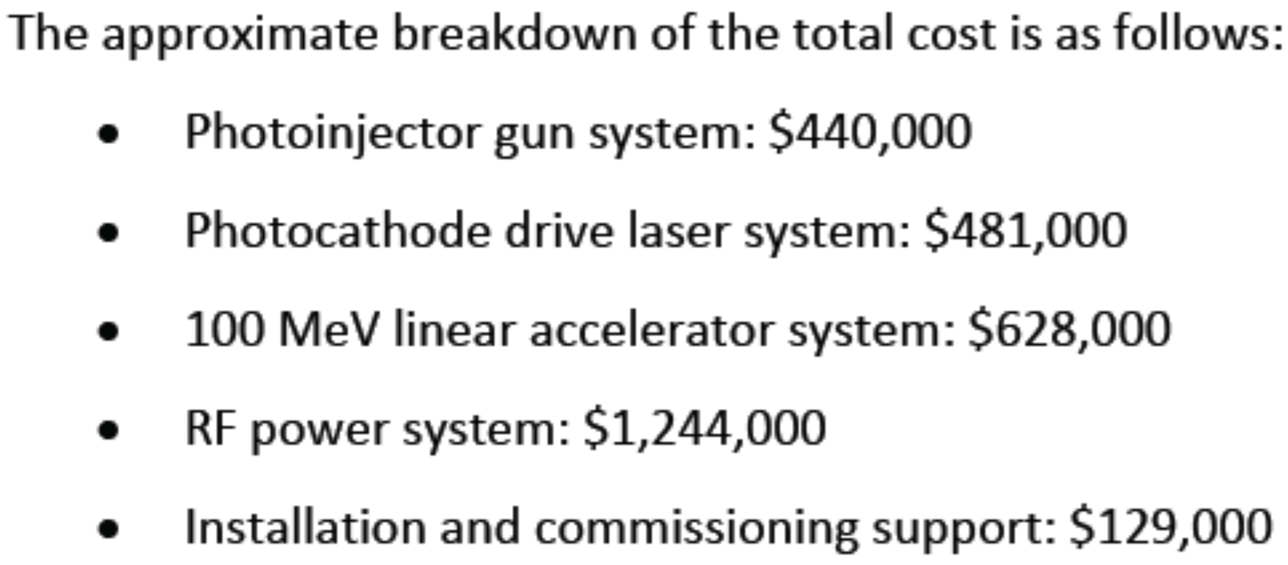


“Turn-key” proposal to LBNE



Item	Value
RF operating frequency	2856 MHz
RF pulse flat-top duration	3 μs
Max. RF input power	10 MW
Max. accelerating gradient	100 MV/m
Max. beam energy at gun output	4.5 MeV
Bunch charge	0.1-1 nC
Repetition rate	10 Hz

RF operating frequency	2856 MHz
RF pulse flat-top duration	3 μs
Max. RF input power	15 MW
Max. accelerating gradient	20 MV/m
Max. energy gain per section	60 MeV
Repetition rate	10 Hz



The approximate breakdown of the total cost is as follows:

- Photoinjector gun system: $440,000
- Photocathode drive laser system: $481,000
- 100 MeV linear accelerator system: $628,000
- RF power system: $1,244,000
- Installation and commissioning support: $129,000