PREX2 Carbon Contamination

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Introduction

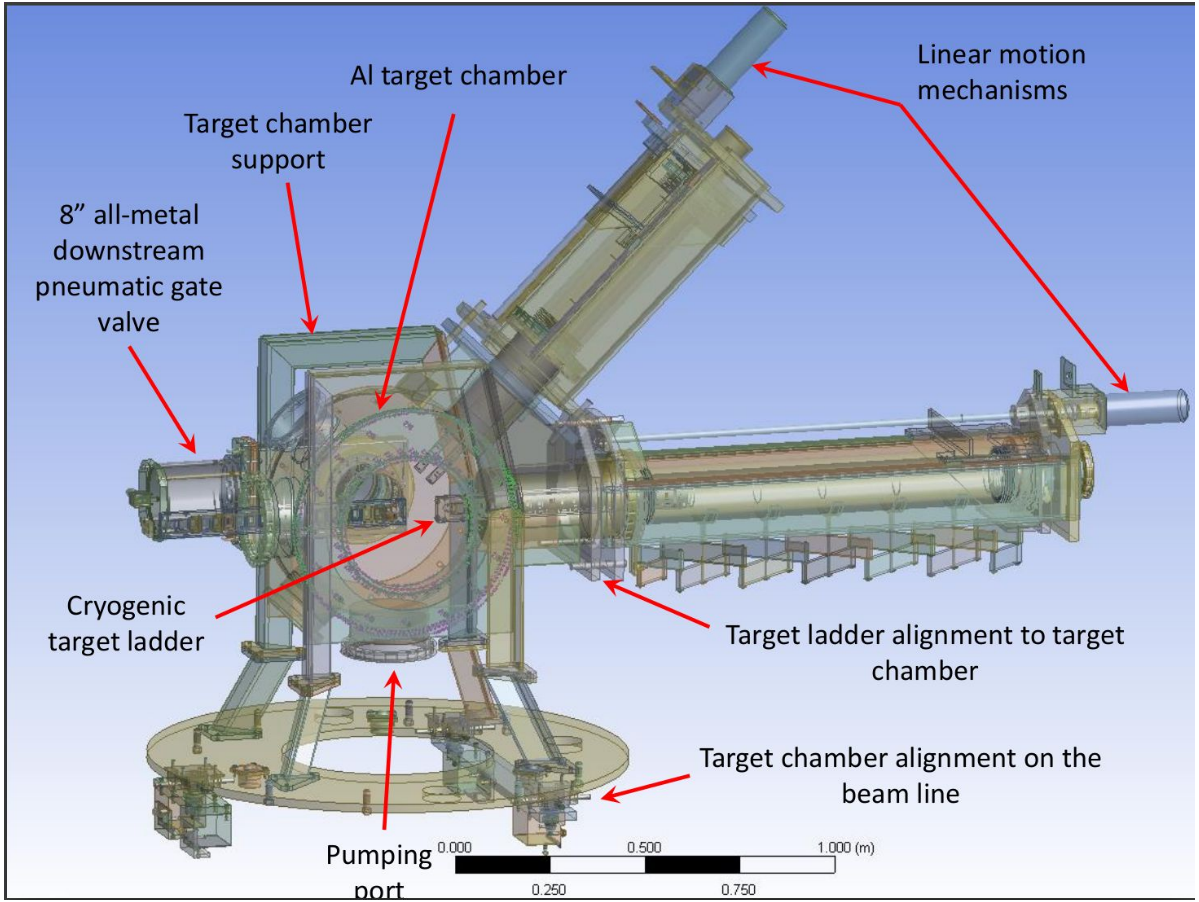
- Carbon Contamination

➢ We used D-Pb-D target for the experiment, rather than pure Pb target; therefore, there is background asymmetry from Carbon

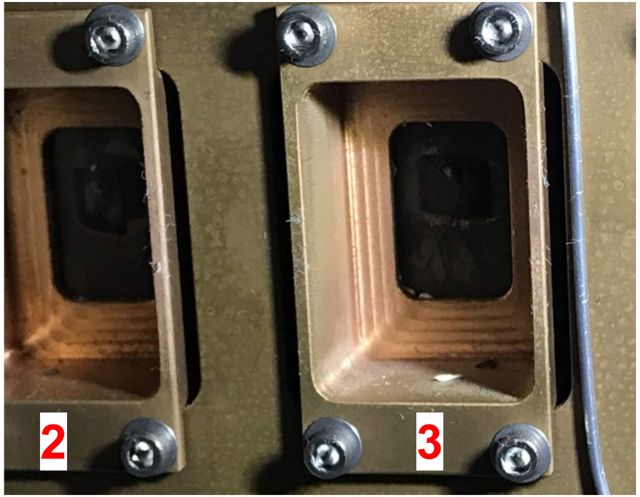
- Why Sandwich Target

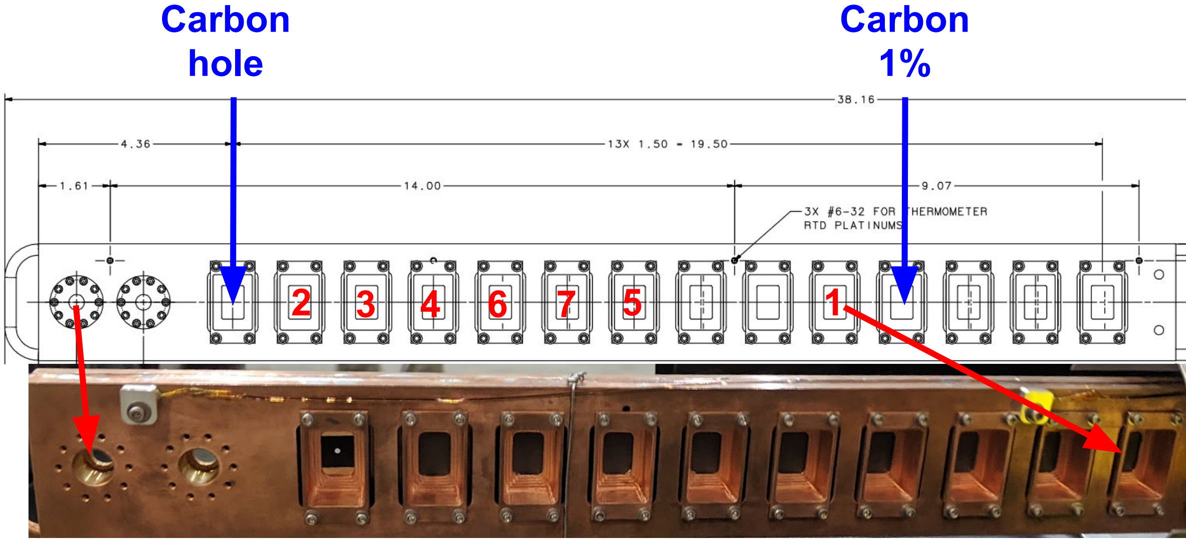
➢ Lead has low melting point, and low thermal conductivity
➢ Diamond foils have excellent thermal conductivity
➢ Clean background from Carbon

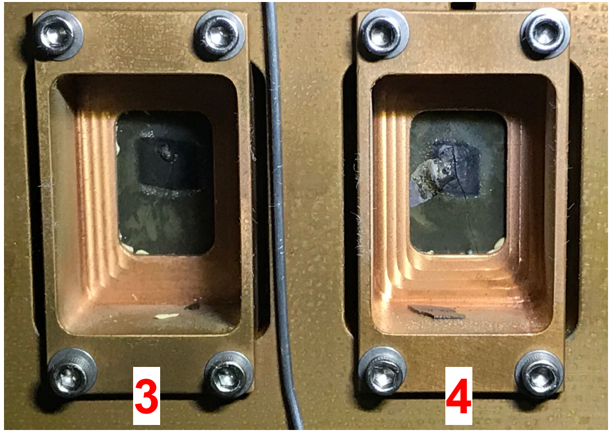
Target Chamber

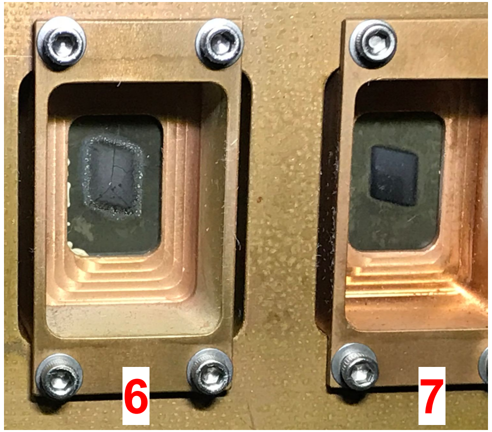


Target Ladder

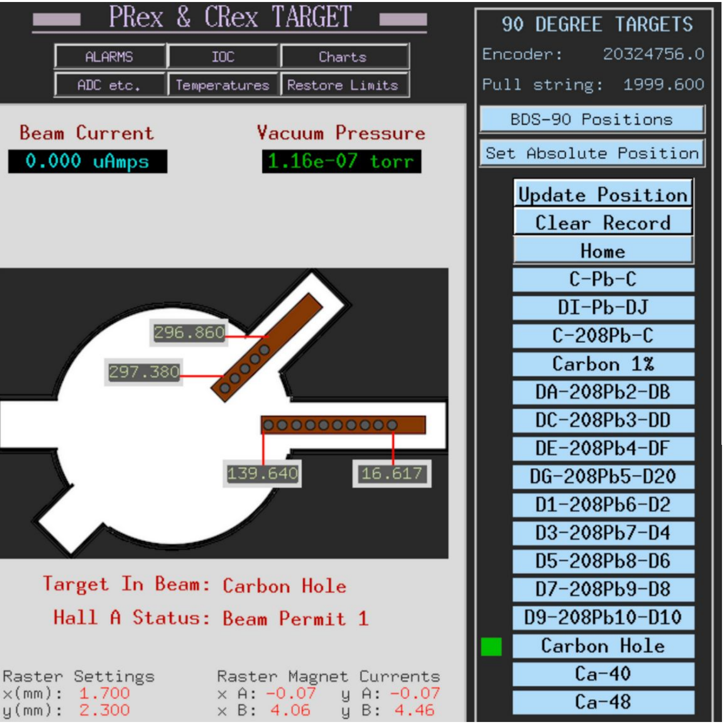


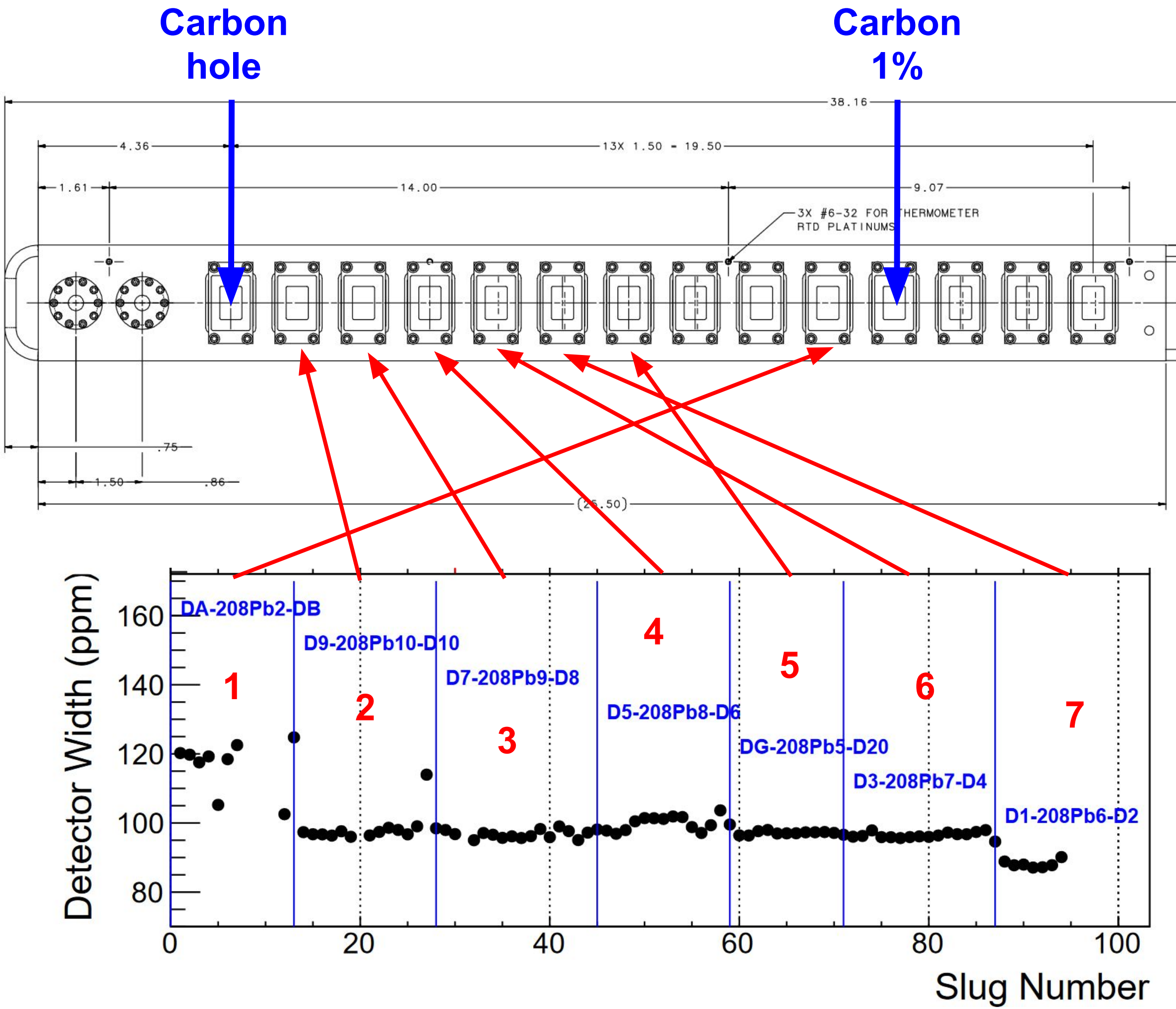






Used targets





Ratio of Thickness

- Data from here, uncertainty is estimated to be 5% (Bob's estimation)
- Assume intact target during data taking
- Variation across targets is very small (3.6% US, 3.8%Pb, 1.6%DS) meaning the weighting won't have much of an effect

Target	Upstream C foil [mg/cm2]		Pb foil [mg/cm2]		Downstream C foil [mg/cm2]	
	value	uncert	value	uncert	value	uncert
D#A-Pb208#2-D#B	89	4.45	632	31.6	88.6	4.43
D#9-Pb208#10-D#10	90	4.5	623	31.15	90	4.5
D#7-Pb208#9-D#8	90	4.5	615	30.75	90	4.5
D#5-Pb208#8-D#6	90	4.5	620	31	90	4.5
D#G-Pb208#5-D#20	86.8	4.34	632	31.6	90	4.5
D#3-Pb208#7-D#4	90	4.5	639	31.95	90	4.5
D#1-Pb208#6-D#2	90	4.5	618	30.9	90	4.5

Carbon background correction

$$A_{PV} = \frac{A_{corr}/P_e - \sum_i A_i f_i}{1 - \sum_i f_i}$$

- A_{corr}: Corrected asymmetry
- P_e: Polarization
- A_i: Background asymmetry
- f_f: Background fraction

- For elastic carbon contamination corrections, we use the Geant4 simulation (g4hrs) to get carbon fraction and asymmetry.
- The carbon fraction estimation from the simulation was also cross checked with other calculations as well as rate estimated from data.

Background fraction

- Determined from a D-Pb-D sandwich target simulation
- Rates obtained in the simulation with:
  - Q1 Collimator cut
  - Track at VDC plane
  - Detector acceptance cut to cut off radiative tail using Δp (= P_{peak} - P) < 2.2 MeV
- Carbon rate (R_C) and Pb rate (R_Pb) reported by the simulation are used directly to calculate the carbon fraction
- Systematic uncertainties estimated for
  - Pb thickness variation (+/- 5%)
  - C thickness variation (+/- 5%)
  - Momentum cut variation (varied from 1.8 to 2.6 MeV)

Background fraction (thickness variation)

- Varied target thickness +/-5% for Pb and C. We got the carbon fraction of 6.3%.

Target thickness variation						
Pb	C	p cut (MeV)	C rate (MHz)	Pb rate (MHz)	R_C/R_{Pb}	f_C
-5%	-5%	2.2	1.26E+02	1.88E+03	6.72E-02	6.30E-02
-5%	0%	2.2	1.34E+02	1.90E+03	7.05E-02	6.59E-02
-5%	5%	2.2	1.38E+02	1.90E+03	7.23E-02	6.75E-02
0%	-5%	2.2	1.22E+02	1.90E+03	6.43E-02	6.04E-02
0%	**0%**	**2.2**	**1.29E+02**	**1.93E+03**	**6.71E-02**	**6.29E-02**
0%	5%	2.2	1.35E+02	1.89E+03	7.11E-02	6.64E-02
5%	-5%	2.2	1.16E+02	1.95E+03	5.94E-02	5.61E-02
5%	0%	2.2	1.22E+02	1.94E+03	6.31E-02	5.93E-02
5%	5%	2.2	1.28E+02	1.91E+03	6.72E-02	6.30E-02

Background fraction (momentum cut scan)

- From Devi's data analysis, the detector edge was found at 1.8-2.2 MeV (LHRS) and 2.0-2.6 MeV (RHRS) away from the elastic peak (varying over runs)
- From the the simulation momentum cut scan in [1.8, 2.6] MeV, we found relatively minor variation in the carbon fraction. Differences are taken as systematic uncertainty.

Pb	C	p cut (MeV)	C rate (MHz)	Pb rate (MHz)	R_C/R_{Pb}	f_C
0%	0%	1.80	1.24E+02	1.86E+03	6.68E-02	6.26E-02
		1.90	1.25E+02	1.87E+03	6.69E-02	6.27E-02
		2.00	1.27E+02	1.89E+03	6.70E-02	6.28E-02
		2.05	1.27E+02	1.90E+03	6.70E-02	6.28E-02
		2.10	1.28E+02	1.91E+03	6.71E-02	6.28E-02
		2.15	1.29E+02	1.92E+03	6.71E-02	6.29E-02
		2.20	**1.29E+02**	**1.93E+03**	**6.71E-02**	**6.29E-02**
		2.25	1.30E+02	1.94E+03	6.72E-02	6.30E-02
		2.30	1.31E+02	1.95E+03	6.73E-02	6.30E-02
		2.35	1.31E+02	1.95E+03	6.73E-02	6.31E-02
		2.40	1.32E+02	1.96E+03	6.74E-02	6.32E-02
		2.60	1.34E+02	1.99E+03	6.74E-02	6.32E-02

Cross Check

For fixed target experiment:

$$R \sim \sigma \times N = \sigma \times \frac{t}{m_X}$$

Where t is the thickness, in unit of mass/area and m_X is the atomic mass for either C or Pb. Their division gives out number of atoms per unit area.

$$\frac{R_C}{R_{Pb}} = \frac{\sigma_C}{\sigma_{Pb}} \times \frac{t_C/m_C}{t_{Pb}/m_{Pb}}$$

Background fraction cross check

Carbon fraction from the simulation: 0.0629 +/- 0.005

Central value (f_C)	Pb thickness variation	C thickness variation	Pcut variation	Total (δf_C)	Rel. error (%)
6.29E-02	2.98E-03	3.53E-03	2.93E-04	4.63E-03	7.36E+00
	-3.55E-03	-2.49E-03	-2.88E-04	4.35E-03	6.91E+00

$$f_C = \frac{R_C}{(R_C + R_{Pb})}$$

Using Chuck's table directly (E0=950MeV, angle=4.8 deg): 0.0657

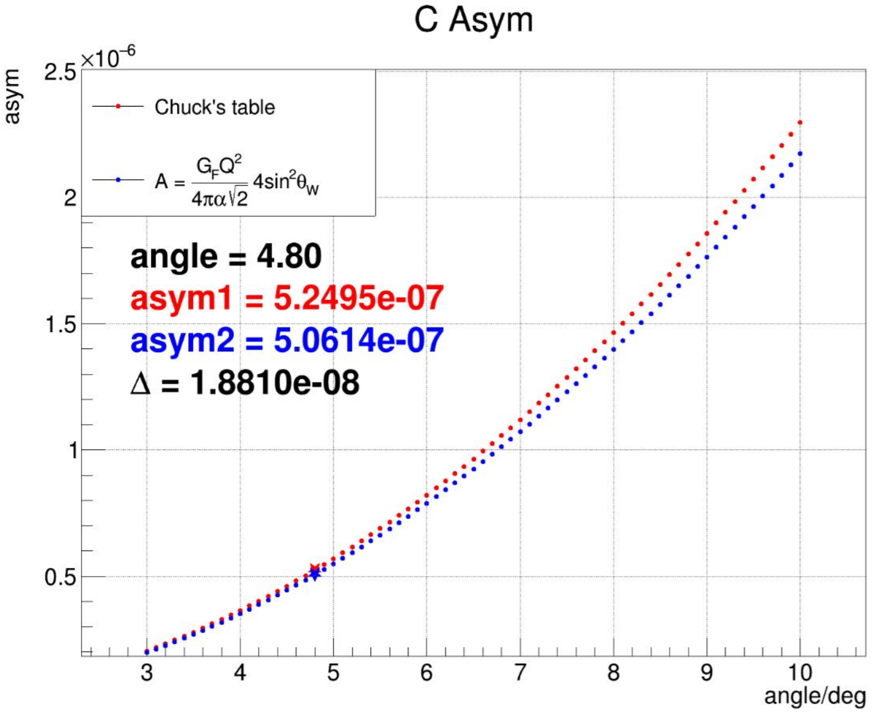
$(t_C/m_C)/(t_{Pb}/m_{Pb})$	$xsec_C$	$xsec_{Pb}$	R_C/R_{Pb}	f_C
4.963	48.001	3386.1	7.04E-02	**6.57E-02**

Estimates from integrating data using DD width: 0.0747

R_C (MHz)	R_{Pb} (MHz)	R_C/R_{Pb}	f_C
163	2019.5	0.0807	**7.47E-02**

Background asymmetry

- Obtained directly from the simulation making use of Chuck H. C tables
  - Seamus confirmed that this also includes Coulomb distortions
  - Cross check with a Standard model Born approximation calculation shows a 3.5% difference at our scattering angle
- The simulation does the appropriate calculation for each scattering (different energy, angle) and we take the rate weighted average
- The asymmetry comes out to be 539 ppb
  - The uncertainty currently was taken as 4% (as in PREX1; i.e. the experimental uncertainty of HAPPEX-He4)



Contribution to A_{PV}

$$A_{PV} = \frac{A_{corr}/P_e - \sum_i A_i f_i}{1 - \sum_i f_i}$$

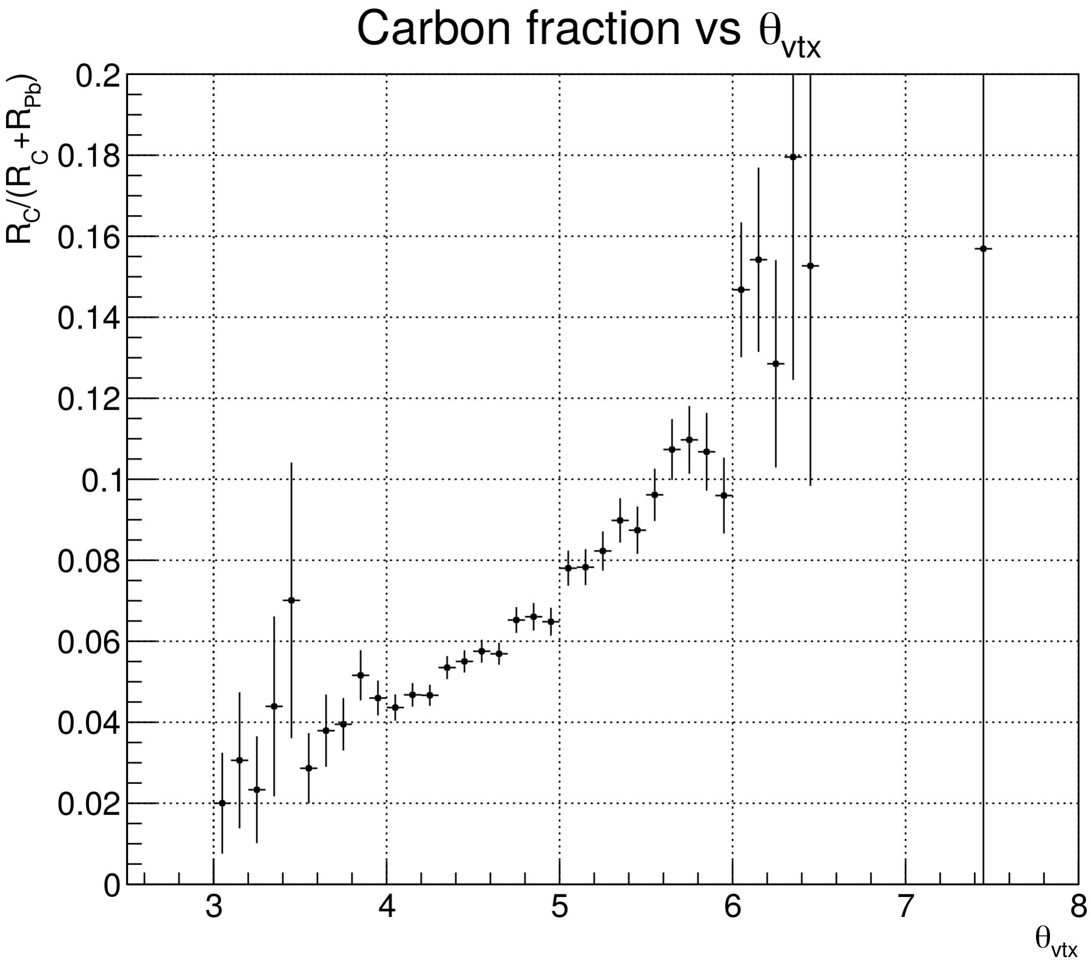
$$\Delta A_{PV} = \sqrt{\sum_j \left(\frac{\partial A_{PV}}{\partial A_j}\Delta A_j\right)^2 + \sum_j \left(\frac{\partial A_{PV}}{\partial f_j}\Delta f_j\right)^2 + \left(\frac{\partial A_{PV}}{\partial P_e}\Delta P_e\right)^2 + \left(\frac{\partial A_{PV}}{\partial A_{corr}}\Delta A_{corr}\right)^2}$$

- The uncertainty from the fraction is negligible to the final systematic
- The uncertainty from the asymmetry currently has a relatively larger contribution (although much smaller than other contributions)

With the HAPPEX He4 4% uncertainty on A_C:

A_{corr}/P_e (ppb)	A_C (ppb)	$\delta A_C/A_C$ (%)	δA_C (ppb)	f_C	δf_C	Rel. error (%) due to f_C	Rel. error (%) due to A_C
549.34	539.36	4	21.574	6.29E-02	4.63E-03	**0.01**	**0.26**

Backup

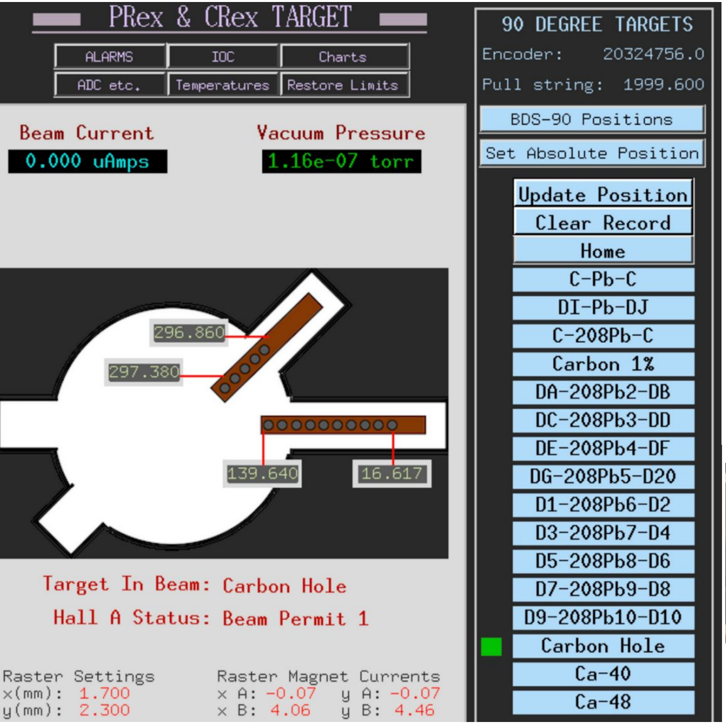


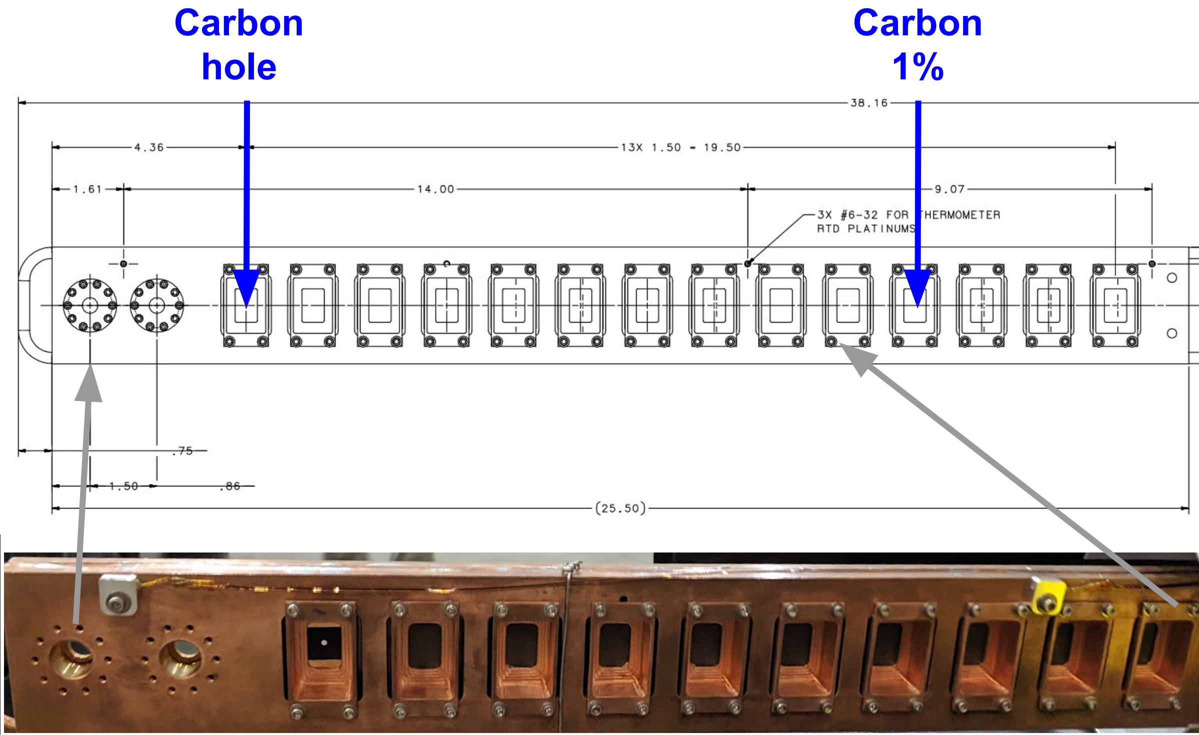
Carbon fraction vs θvtx
R_C/(R_C+R_Pb)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
3
4
5
6
7
8
θvtx

Resources

- Sanghwa’s talk: https://prex.jlab.org/DocDB/0004/000413/002/prex2_target.pdf
- Dave Meekins’ measurements **(use this first)**: https://prex.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=446
- Bob’s measurements: https://prex.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=357
- Meekins’ destroyed target pictures: https://prex.jlab.org/cgi-bin/DocDB/private/ShowDocument?docid=427
- Silviu’s CFD simulations: https://prex.jlab.org/DocDB/0001/000141/001/Pb350foil_24apr2018.pdf

Used targets





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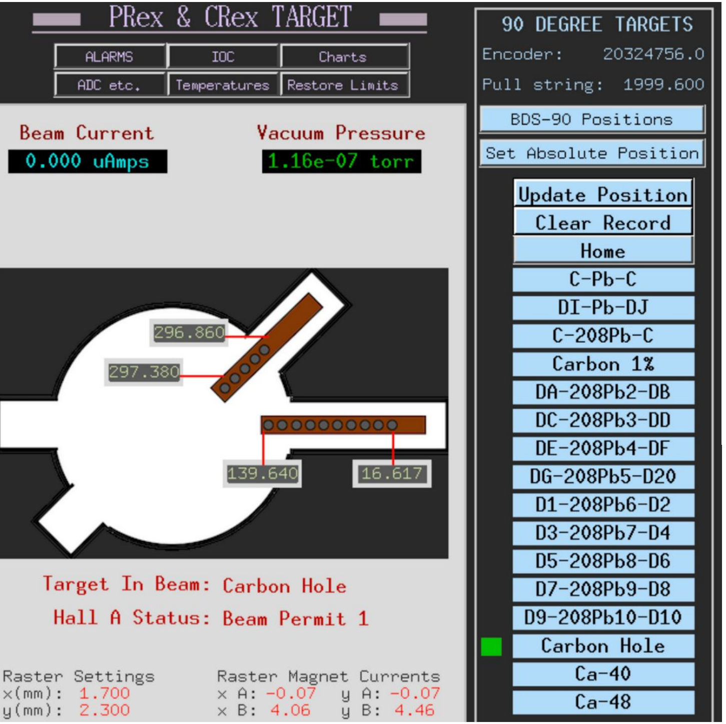

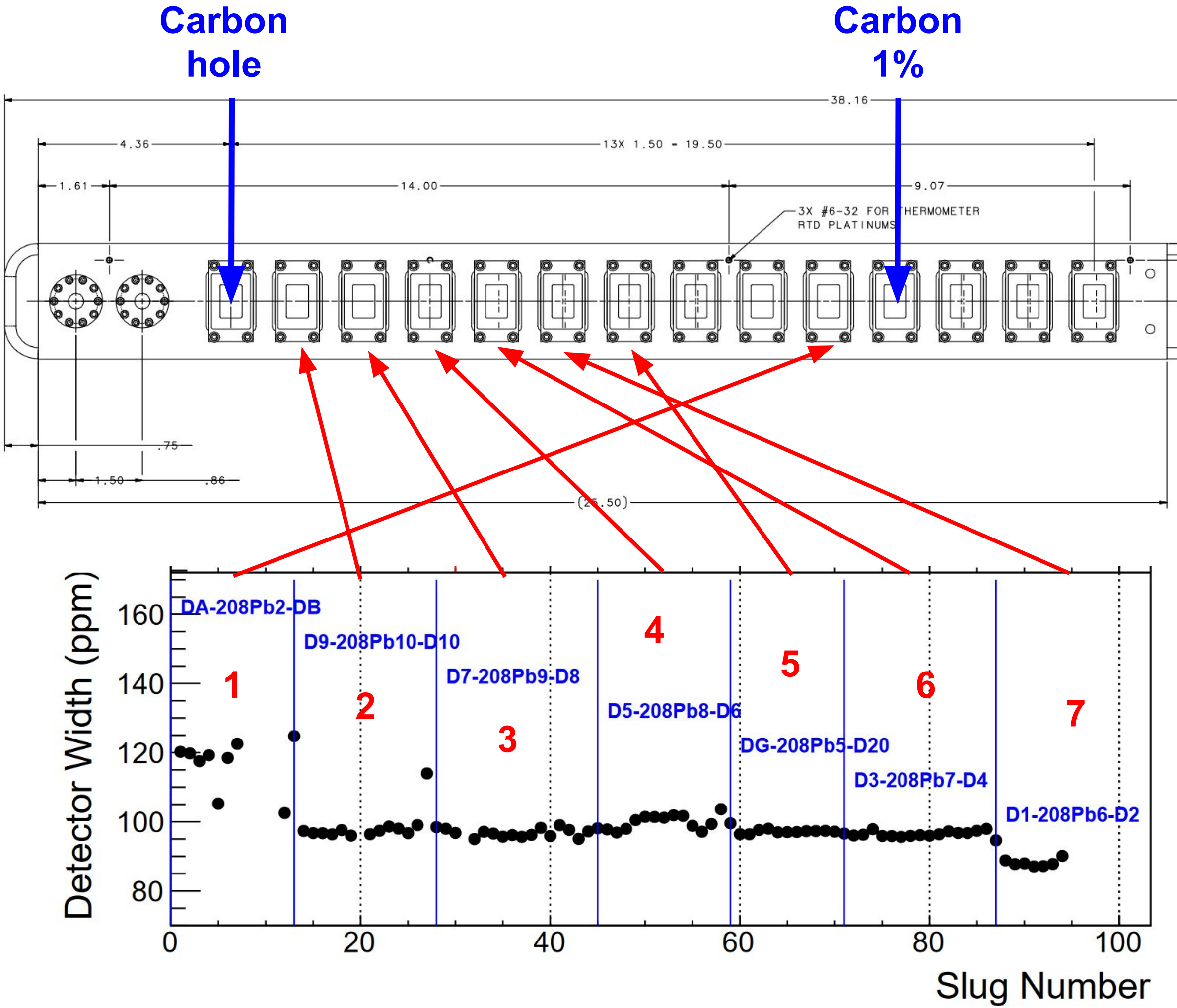

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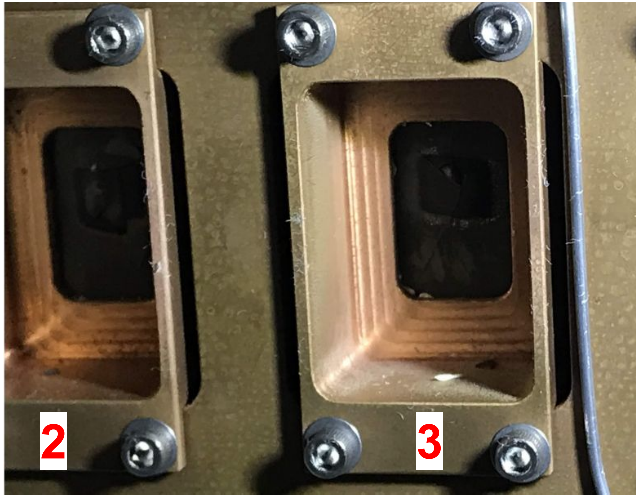
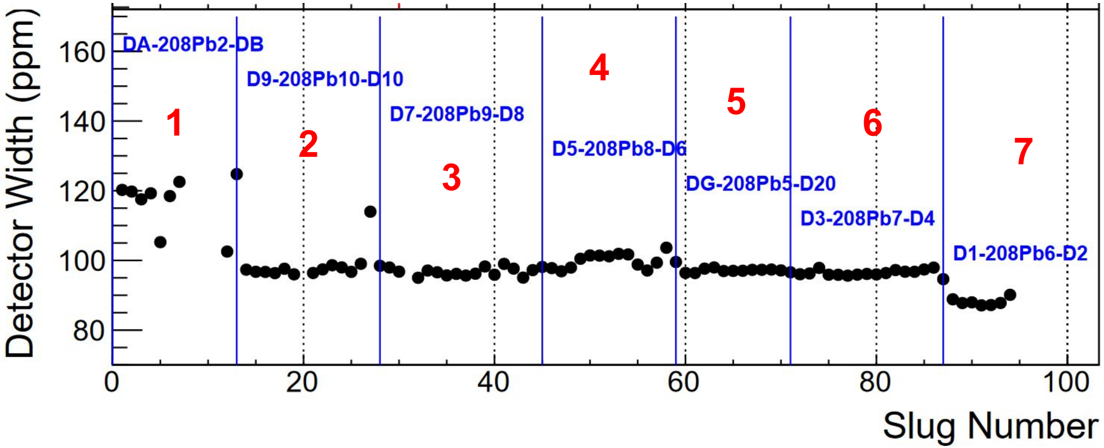
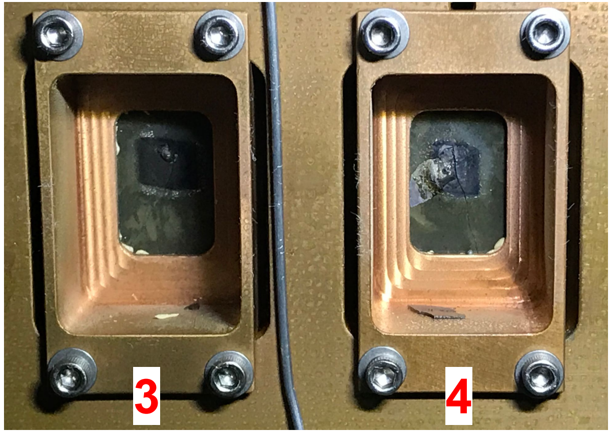
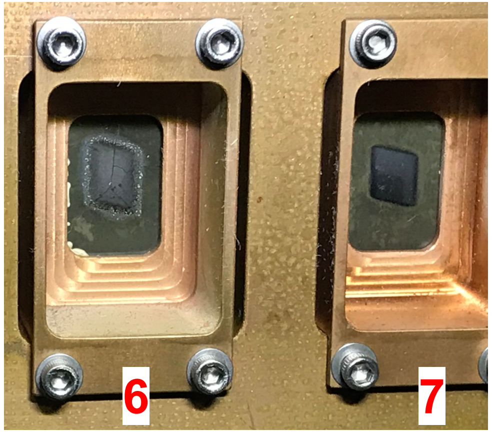
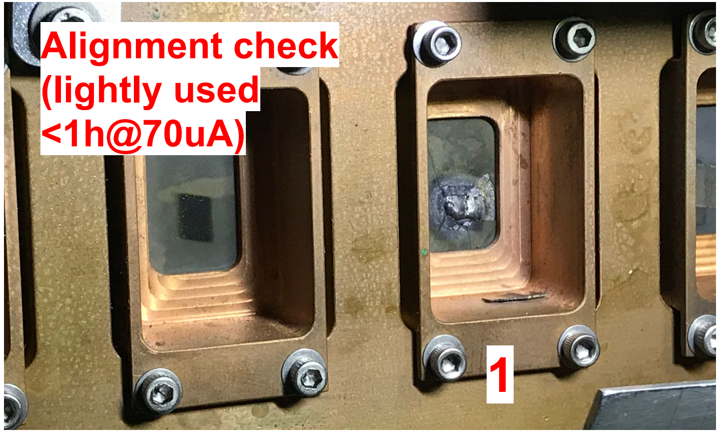










Target change

	Radiation levels before change				Radiation levels after change				MD widths (reg_asym_us_avg) [ppm]		
change time	RadCon mon 1	RadCon Mon 2	Compton no-laser rates	Collimator delta T at full current	RadCon mon 1	RadCon Mon 2	Compton no-laser rates	Collimator delta T at full current	before change	after change	Run numbers for optics/spot++ runs
2019.7.10 ~12:00	~5700 (50 uA)	~48800	0	~9	~6300 (50 uA)	~52400	0	~11		run 3140 (50 uA): 120.91	1873/21000
2019.7.26 ~07:37	~8200 (60 uA)	~67400	0	~22.4	~8400 (70 uA)	~77500	0	~14	run 3636: 135.211	run 3649: 96.1003	2113
2019.8.3 ~09:00	~10100 (60 uA)	~85800	0	~25	~8600 (70 uA)	~75900	0	~13	run 3821: 122.54	run 3822: 90.8972	2079-2080/21 197-21198
2019.8.14 ~20:46	~10500 (70 uA)	~88700	~335000	~25	~8700 (70 uA)	~76700	~246000	~15	run 4145: 105.565	run 4148: 91.5341	2122/21268
2019.8.21 ~04:35	~9800 (70 uA)	~83500	~256000	~25	~8800 (70 uA)	~77900	~185000	~12	run 4370: 115.1	run 4372: 91.4265	2129-2130
2019.8.27 ~16:42	~10200 (70 uA)	~88000	~40100	~21	~9500 (70 uA)	~75300	~349000	~18	run 4596: 91.5405	run 4621: 91.8039	21309-21310
2019.9.6 ~14:30	~10300 (73 uA)	~86100	~385000	~20	~8700 (70 uA)	~74300	~299000	~14	run 4864: 91.4956	run 4865: 92.3418	2311-2312/21 430-21431

Weight Target Thickness

Because we used more than one target in the experiment, we weight the ratio of thickness of each target by the main detector error from that target

$$\frac{t_C}{t_{Pb}} = \sum_i w_i \frac{t_{i,C}}{t_{i,Pb}} \quad t_C = t_{C_{us}} + t_{C_{ds}}$$

Target name	weight factor [main det error/ppb]	Ratio of t/A	weighted ratio
D#A-Pb208#2-D#B	42.743	4.866	0.636
D#9-Pb208#10-D#10	33.3465	5.003	0.740
D#7-Pb208#9-D#8	28.9264	5.068	0.805
D#5-Pb208#8-D#6	33.5835	5.027	0.741
D#G-Pb208#5-D#20	36.3435	4.844	0.687
D#3-Pb208#7-D#4	32.7936	4.878	0.728
D#1-Pb208#6-D#2	47.6238	5.043	0.625
			4.963

Cross Check

For fixed target experiment:

$$R \sim \sigma \times N = \sigma \times \frac{t}{m_X}$$

Where t is the thickness, in unit of mass/area and m_X is the atomic mass for either C or Pb. Their division gives out number of atoms per unit area.

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \cos^2 \frac{\theta}{2}}{4E^2 \sin^4 \frac{\theta}{2}} \times Z^2 \times F^2(Q^2)$$

$$\frac{R_C}{R_{Pb}} = \boxed{\frac{\sigma_C}{\sigma_{Pb}} \times \frac{t_C/m_C}{t_{Pb}/m_{Pb}}} = \boxed{\frac{Z_C^2}{Z_{Pb}^2} \times \frac{F_C^2}{F_{Pb}^2} \times \frac{t_C/m_C}{t_{Pb}/m_{Pb}}}$$

All runs for “central” cut (cut at quartz edge) - Devi

RunR	q_edge	Qsq	Qsq_rms	q_dge_rel	Acc_fr
21108	0.9454	0.0063066	0.0011835	**0.0021033**	0.4887
21121	0.9454	0.0063100	0.0011860	**0.0020789**	0.5128
21185	0.9454	0.0063122	0.0011863	**0.0021332**	0.5059
21344	0.9458	0.0063041	0.0011702	**0.0022917**	0.5049
21412	0.9456	0.0063032	0.0012069	**0.0020230**	0.5058
21413	0.9455	0.0062968	0.0011947	**0.0018824**	0.5044
21414	0.9456	0.0063005	0.0012003	**0.0018020**	0.4952
21415	0.9456	0.0062983	0.0012000	**0.0019123**	0.5167

All runs with “central” cut (cut at quartz edge)

RunL	q_edge	Qsq	Qsq_rms	q_dge_rel	Acc_fr
1983	0.9468	0.006491	0.001241	**0.002627**	0.4924
1996	0.9472	0.006471	0.001223	**0.002197**	0.5054
2052	0.9474	0.006472	0.001217	**0.002057**	0.5208
2199	0.9478	0.006517	0.001274	**0.002312**	0.4987
2291	0.9474	0.006510	0.001260	**0.002269**	0.4980
2292	0.9474	0.006509	0.001258	**0.002081**	0.5006
2293	0.9474	0.006512	0.001263	**0.002041**	0.5196
2294	0.9474	0.006506	0.001255	**0.002189**	0.5098

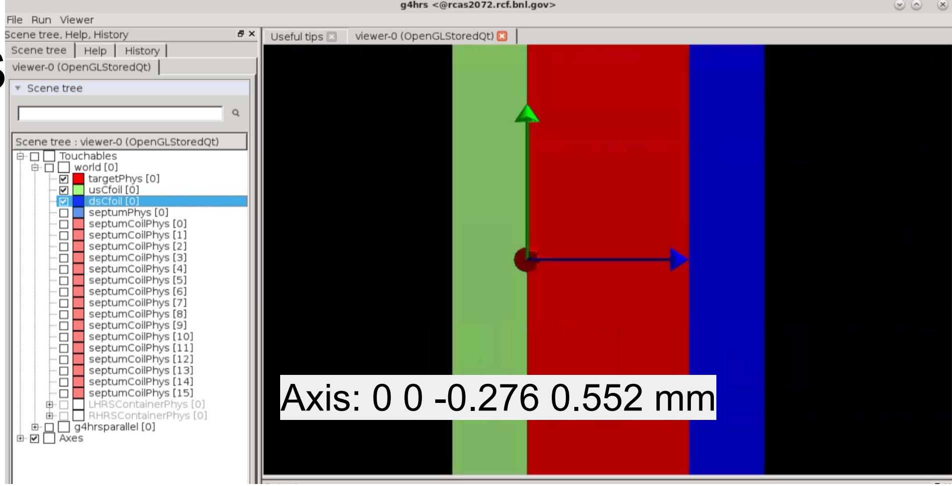
Xsection

- Get values from Chuck H. table:
  - C: https://github.com/sbujlab/g4hrs/blob/master/c12_fsu.dat
  - Pb: https://github.com/sbujlab/g4hrs/blob/master/horpb.dat
- Use E = 0.95 GeV, scattering angle = 4.8 degree

Adding CPbC targets to sims

```
//Define diamond
a = 12.01 * g/mole;
density = 3.515*g/cm3;
diamond = new G4Material("Diamond", z=6, a, density);

//lead208
a = 207.9766521*g/mole;
density = 11.38*g/cm3;
lead208 = new G4Material(name="Lead208", z=82., a, density);
```



- CAREFUL: changing the thickness/position of the Pb target in the macro compared to what is hardcoded will result in overlaps.
- Asymmetry lookup table updated to check for C12 in the Nuclear Elastic generator

```
double sigma = fDatabase->Interpolate(beamE,th,0,0)*millibarn;
if(thisA==12)
  sigma = fDiamondDB->Interpolate(beamE,th,0,0)*millibarn;
```

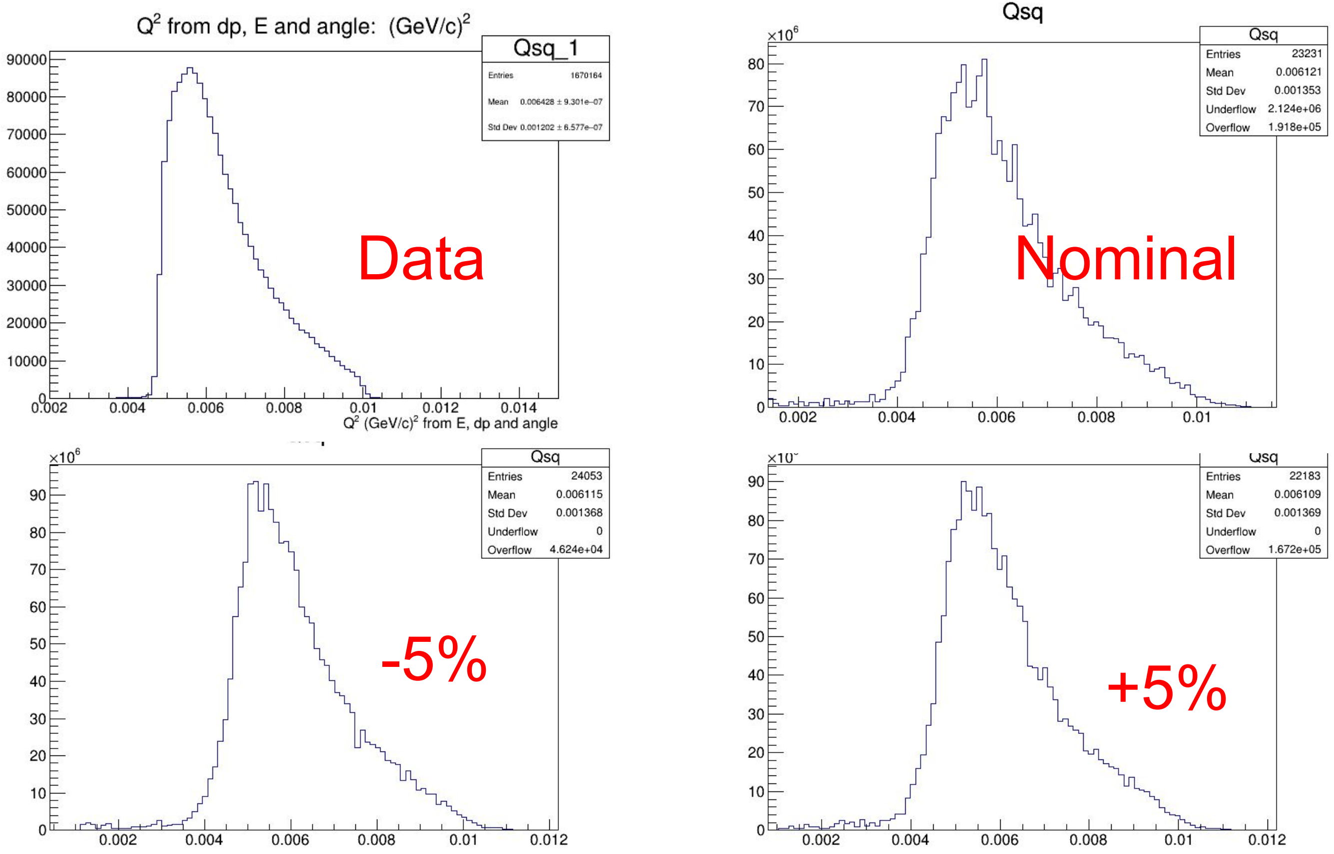
```
G4double APV = fDatabase->Interpolate(beamE,th,0,1);
G4double APV1 = fDatabase->Interpolate(beamE,th,1,1);
if(thisA==12){
  APV  = fDiamondDB->Interpolate(beamE,th,0,1);
  APV1 = fDiamondDB->Interpolate(beamE,th,1,1);
```

Cut on Events

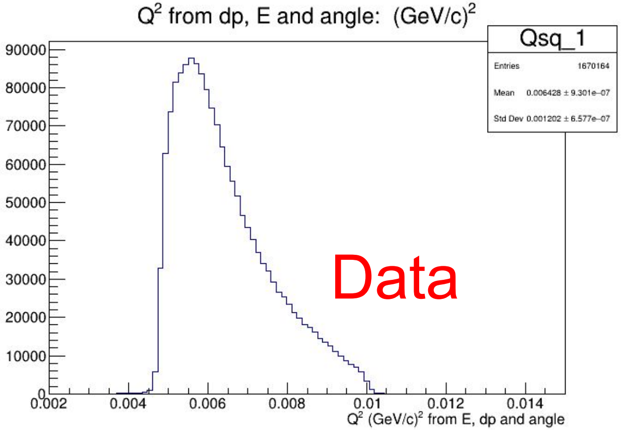
```
xcol != -333
&& CollimatorL(xcol, ycol)  // Q1 collimator
// && xfp != -333  // focal plane cut
&& xvdc != -333 // vdc sees the track
&& (nuclA == 12 || nuclA == 208)
&& epeak - Pz < 2.2    // radiative tail cut; cut only on lower side
```

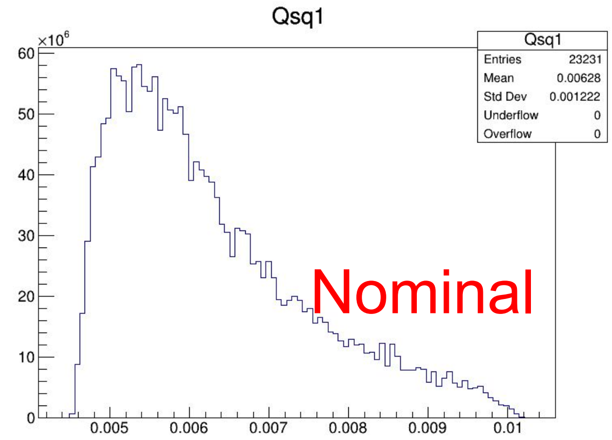
- Q1 collimator cut
- Vdc cut
- C/Pb nuclei
- Radiative tail cut, epeak is decided separately for each thickness configuration

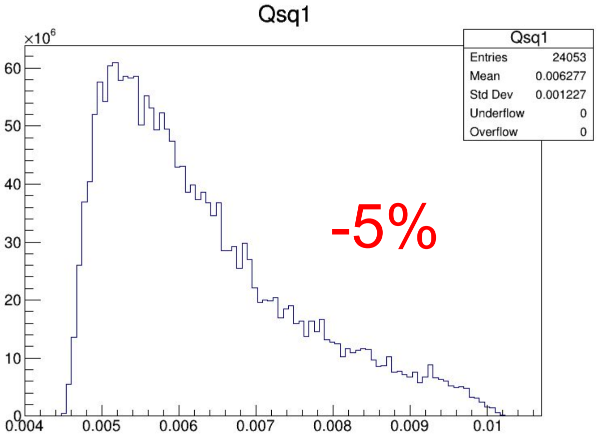
Q2 comparison

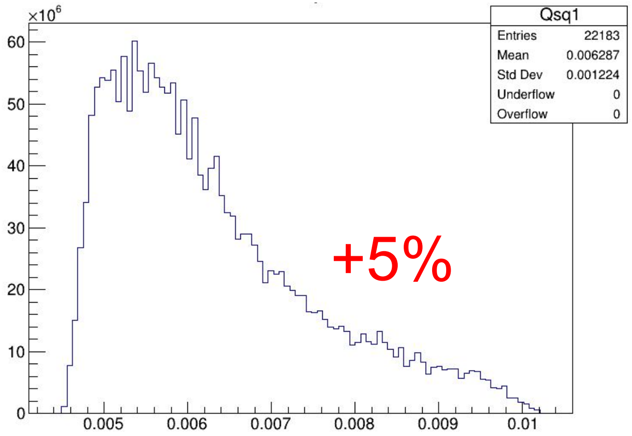


Q2 (post-vertex) comparison









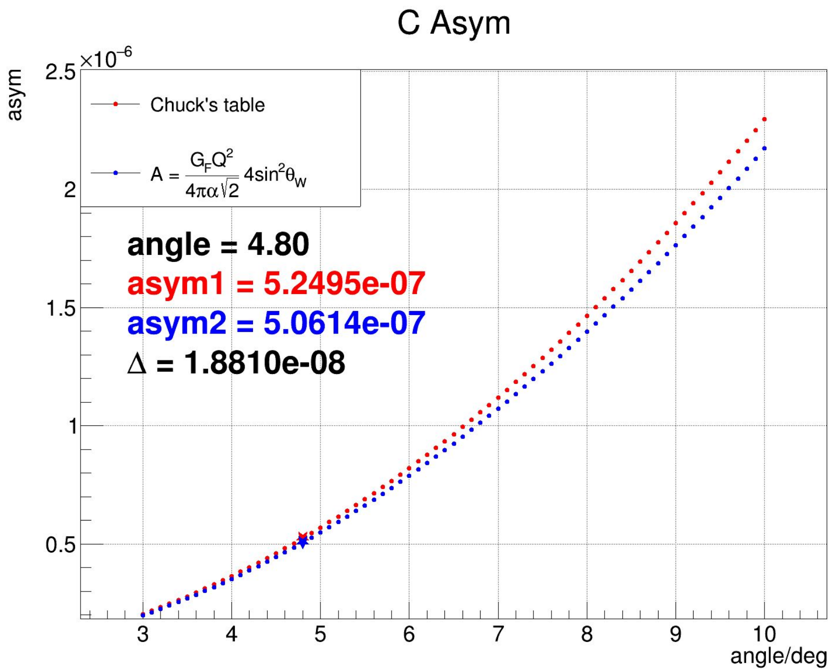
Vertex Q2 vs post-vertex Q2

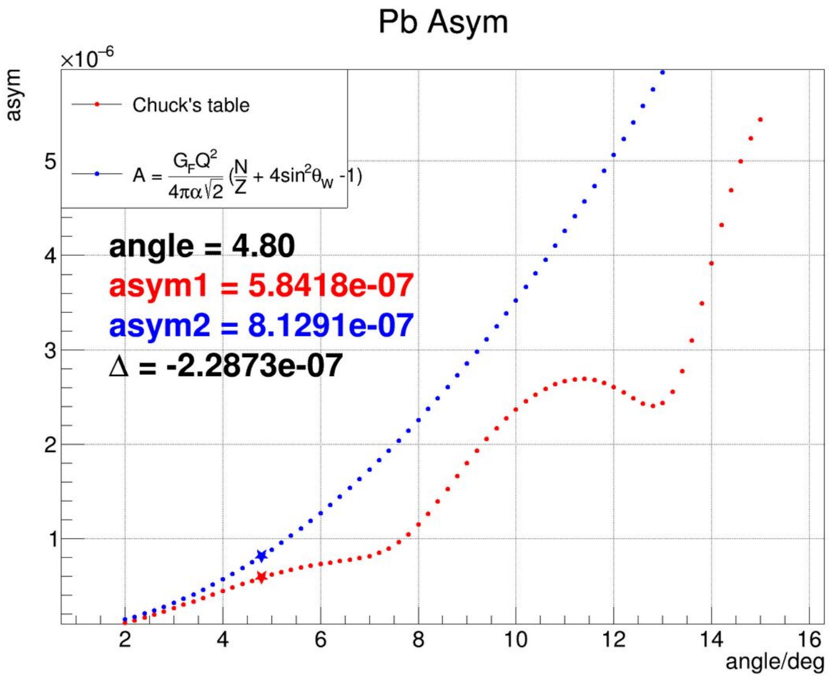
	data	nominal	-5%	+5%
Vertex-Q2	0.006428	0.00612	0.00611	0.00611
Post Vertex-Q2		0.00628	0.00628	0.00629

Asym of Carbon

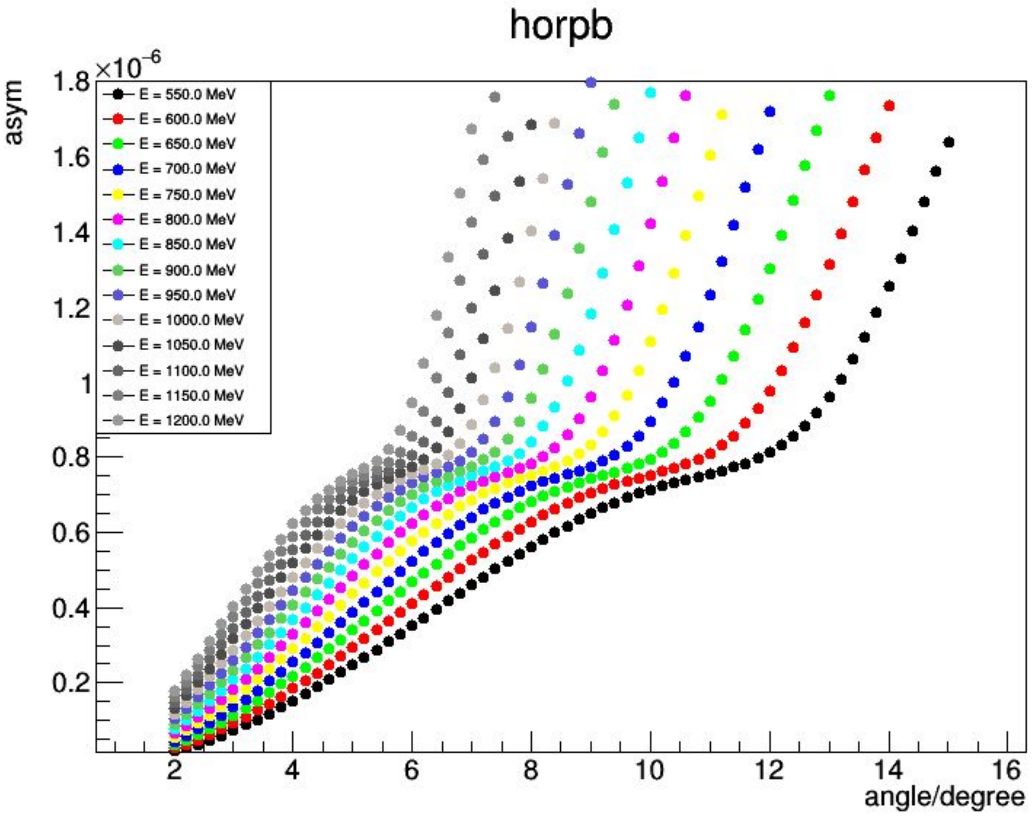
	Nominal	-5% Pb	+5% Pb
Pb thickness/mm	0.552	0.5244	0.5796
Angle (deg)	4.8404	4.8332	4.8345
Energy (MeV)	949.0551	949.0786	949.0311
Asym (ppm)	0.5394	0.5378	0.5381

Asym: Comparison between Chuck's table and Tree level computation





Asym of Pb


horpb
asym
$\times 10^{-6}$
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
E = 550.0 MeV
E = 600.0 MeV
E = 650.0 MeV
E = 700.0 MeV
E = 750.0 MeV
E = 800.0 MeV
E = 850.0 MeV
E = 900.0 MeV
E = 950.0 MeV
E = 1000.0 MeV
E = 1050.0 MeV
E = 1100.0 MeV
E = 1150.0 MeV
E = 1200.0 MeV
2
4
6
8
10
12
14
16
angle/degree

Uncertainty Propagation

$$\text{for } x = A \times (/) B: \quad \sigma_x = |x| \times \sqrt{\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2}$$

$$\text{for } x = A + (-) B: \quad \sigma_x = \sqrt{\sigma_A^2 + \sigma_B^2}$$

let $r = \frac{R_C}{R_{Pb}}, m = \frac{\sigma_C}{\sigma_{Pb}}, n = \frac{t_C/A_C}{t_{Pb}/A_{Pb}}$ (take A_C and A_{Pb} as constant)

$$\sigma_n = |n| \times \sqrt{\left(\frac{\sigma_{t_C}}{t_C}\right)^2 + \left(\frac{\sigma_{t_{Pb}}}{t_{Pb}}\right)^2} \qquad \sigma_{t_C} = \sqrt{\sigma_{t_{C_{us}}}^2 + \sigma_{t_{C_{ds}}}^2}$$

$$\sigma_r = |r| \times \sqrt{\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_n}{n}\right)^2}$$