TRIUMF	UNIVERSITY OF ALBERTA EDMONTON, ALBERTA	
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Author GM Stinson		
Subject Extraction data for beam line 2A		

1. Introduction

This note presents a complete set of extraction parameters for beam line 2A. The data was requested primarily to develop an analytic expression for the field setting of the combination magnet of the beam line.

2. Extraction data

Extraction parameters for beam line 2A have been provided by R. Lee[1)] for an energy range from 470 MeV to 510 MeV. In table 1 we list the stripping radius and angle and the combination magnet field that he has calculated over this energy range. Table 2 lists the transfer matrix elements that were calculated.

3. Analysis of the field versus energy extraction data

The program PLOTDATA[2)] was used to fit the calculated combination magnet fields to expressions that were linear, quadratic and cubic function of the extracted energy. The results of the fits are given below; in the expressions, the field B is given in kG for energies E in MeV.

Type of fit	Fitted expression
Linear	$B = 73.66786 - 14.98534\left[\frac{E}{100}\right]$
Quadratic	$B = 62.05789 - 10.24381\left[\frac{E}{100}\right] - 0.4838294\left[\frac{E}{100}\right]^2$
Cubic	$B = 1153.09 - 678.6901\left[\frac{E}{100}\right] + 135.9815\left[\frac{E}{100}\right]^2 - 9.283356\left[\frac{E}{100}\right]^3$

Figures 1, 2 and 3 show the linear, quadratic and cubic fits, respectively, to the calculated data. On the scales presented there is little difference to be seen. However, as shown in figure 4—a plot of the *differences* between the calculated and fitted fields—the cubic fit is the best (as one should expect).

From the above expressions the energy at which the combination magnet field reverses is calculated to be 491.600 MeV from the linear fit, 491.644 MeV from the quadratic fit and 491.671 MeV from the cubic fit.

From this analysis it is recommended that the cubic fit to the 2A combination fields be used. The calculated and fitted fields are listed in table 3.

4. Measured R versus energy extraction data

In late april and early May of 1997 beam was extracted from extraction port 2A over an energy region from 472 MeV to 510 MeV with *no* combination magnet in place[3)]. Following these measurements the combination magnet was installed.

Measurements without the combination magnet were made with three wire chambers. The first was located at the cross-over point of the combination magnet and had 16 wires with a 3mm spacing in each of the horizontal and vertical planes. The second was located just downstream of the 2AQ1/2AQ2 quadrupole doublet and had 32 wires with a spacing of 2mm in each of the horizontal and vertical planes. The third was located approximately 2 m downstream of the second, just upstream of a temporary beam dump. This monitor had 32 wires with a 3 mm spacing in each of the horizontal and vertical planes. Beam currents extracted were less than 10 nA.

Table 4 lists the energies and R, L and z values that were obtained. The energies of the extracted beams were measured by shadowing the stripper foil with the high energy probe.

PLOTDATA was again used to fit the measured extraction energy and the R value of the extraction mechanism (assuming that $z = 0$). Figure 5 shows a linear fit of energy versus R; the fitted expression has the equation

Type of fit	Fitted expression
Linear	$E = 1062.069 + 5.795033\,\mathrm{R}$

with E in MeV and R in inches. Figure 6 shows the fit to R as a function of energy. This was fit to both linear and quadratic expressions with the following results.

Type of fit	Fitted expression
Linear	$R = 183.2485 - 0.17513\,E$
Quadratic	$R = 122.758 + 0.07389148\,E - 0.0002507275\,E^2$

where again E is in MeV and R is in inches.

5. Measured field data

Measurement of the B-I data for the combination magnet was done by D. Evans in early 1997 [4)]. The raw data collected by him is reproduced in the leftmost two columns of table 5. Figure 7 is a plot of this raw data. PLOTDATA was again used to fit this data as linear, quadratic and cubic functions of current. The following expressions were obtained for the three functional forms.

Type of fit	Fitted expression
Linear	$B = 0.1505329 + 1.852974\left[\frac{I}{100}\right]$
Quadratic	$B = -0.1502813 + 2.149066\left[\frac{I}{100}\right] - 0.05459045\left[\frac{I}{100}\right]^2$
Cubic	$B = 0.05394736 + 1.80503\left[\frac{I}{100}\right] + 0.09241018\left[\frac{I}{100}\right]^2 - 0.01781268\left[\frac{E}{100}\right]^3$

with B in kG and I in Amperes. Table 6 lists the results of the fits and figure 8 shows the cubic fit to the data.

Because the energy range of extraction is between 470 MeV and 510 MeV the 'useful' range of combination magnet fields lies between ± 4 kG. The data listed in the rightmost two columns of table 5 correspond to this energy range. Figure 9 is a plot of this field-current relationship. The data was then fitted to give more accurate predictions of the fields in the energy range of interest, again using PLOTDATA to obtain expressions for the fields as linear, quadratic and cubic functions of current. The resulting expressions are listed below.

Type of fit	Fitted expression
Linear	$B = -0.0157272 + 1.957545\left[\frac{I}{100}\right]$
Quadratic	$B = -0.03624995 + 1.995333\left[\frac{I}{100}\right] - 0.01433335\left[\frac{I}{100}\right]^2$
Cubic	$B = -0.1340001 + 2.305834\left[\frac{I}{100}\right] - 0.29800038\left[\frac{I}{100}\right]^2 + 0.07666675\left[\frac{E}{100}\right]^3$

with B in kG and I in Amperes. Table 7 lists the results of the fits and figure 10 shows the quadratic fit to the data.

References

1. R. Lee, *Private communication*, TRIUMF, May 6, 1997.
2. J. L. Chuma, *Plotdata Command Reference Manual*, TRIUMF Report TRI-CD-87-03b, TRIUMF, June 1991.
3. A. Hurst, J. Kaminski and G. M. Stinson, TRIUMF, May, 1997.
4. D. Evans, *Private communication*, TRIUMF, March, 1997.

Table 1
Stripping radius and angle and calculated combination magnet fields for beam line 2A

Energy (MeV)	Stripping coordinates Radius (in.)	θ (°)	Combination magnet field (kG)
470	300.137	306.413	3.24704
471	300.141	306.576	3.09329
472	300.146	306.739	2.94113
473	300.150	306.900	2.78680
474	300.154	307.060	2.63448
475	300.158	307.219	2.48425
476	300.162	307.379	2.33002
477	300.166	307.539	2.17732
478	300.170	307.696	2.02744
479	300.174	307.852	1.87581
480	300.177	308.008	1.72584
481	300.181	308.163	1.57662
482	300.185	308.317	1.42645
483	300.189	308.470	1.27745
484	300.192	308.621	1.13126
485	300.195	308.771	0.98253
486	300.199	308.922	0.83537
487	300.202	309.071	0.68998
488	300.205	309.221	0.54102
489	300.208	309.370	0.39516
490	300.211	309.520	0.24779
491	300.215	309.670	0.09830
492	300.218	309.819	−0.04883
493	300.221	309.969	−0.19727
494	300.224	310.118	−0.34632
495	300.227	310.267	−0.49428
496	300.230	310.417	−0.64355
497	300.233	310.565	−0.79346
498	300.237	310.715	−0.94312
499	300.240	310.864	−1.09280
500	300.243	311.013	−1.24456

Table 1 (Continued)

Stripping radius and angle and calculated combination magnet fields for beam line 2A

Energy (MeV)	Stripping coordinates Radius (in.)	θ (°)	Combination magnet field (kG)
501	300.246	311.162	−1.39349
502	300.250	311.311	−1.54458
503	300.252	311.463	−1.69744
504	300.255	311.615	−1.85137
505	300.258	311.770	−2.00631
506	300.264	311.921	−2.16272
507	300.268	312.074	−2.31634
508	300.271	312.230	−2.47797
509	300.276	312.389	−2.63902
510	300.280	312.552	−2.80377

Table 2
Transfer matrix elements for beam line 2A

Energy (MeV)	Horizontal transfer matrix elements					
	R_{11} (cm/cm)	R_{12} (cm/mr)	R_{16} (cm/%)	R_{21} (mr/cm)	R_{22} (mr/mr)	R_{26} (mr/%)
470	−0.00697	0.328463	1.41816	−3.1589	0.16192	2.3764
471	−0.03095	0.326957	1.41315	−3.1443	0.15899	2.3786
472	−0.01160	0.328881	1.40749	−3.2037	0.16420	2.3792
473	−0.00965	0.327717	1.40333	−3.1587	0.16210	2.3832
474	−0.03029	0.326502	1.38757	−3.1230	0.15979	2.3602
475	−0.00918	0.328413	1.39543	−3.1201	0.16518	2.3916
476	−0.01106	0.327107	1.38925	−3.1468	0.16282	2.3912
477	−0.03237	0.325777	1.37422	−3.1752	0.16043	2.3700
478	−0.01346	0.327616	1.38053	−3.1026	0.16538	2.3975
479	−0.01137	0.326531	1.37574	−3.0983	0.16355	2.3998
480	−0.03099	0.325377	1.36150	−3.1767	0.16141	2.3804
481	−0.01608	0.327069	1.36757	−3.1007	0.16645	2.4071
482	−0.01419	0.325969	1.36115	−3.0885	0.16460	2.4056
483	−0.03072	0.325180	1.34868	−3.1606	0.16344	2.3897
484	−0.00860	0.326967	1.35484	−3.0915	0.16820	2.4161
485	−0.05105	0.324831	1.34963	−3.0846	0.16404	2.4170
486	−0.03118	0.324854	1.33633	−3.1598	0.16470	2.3994
487	−0.01160	0.326741	1.34164	−3.0770	0.16984	2.4234
488	−0.05137	0.324587	1.33730	−3.0721	0.16566	2.4261
489	−0.01653	0.325092	1.33255	−3.1519	0.16753	2.4277
490	−0.01551	0.326098	1.32879	−3.0677	0.17049	2.4314
491	−0.05282	0.323834	1.32459	−3.0692	0.16620	2.4346
492	−0.01565	0.324615	1.32298	−3.1477	0.16858	2.4434
493	−0.01996	0.325308	1.31608	−3.0572	0.17108	2.4406
494	−0.05712	0.323120	1.31197	−3.0998	0.16729	2.4436
495	−0.02306	0.323733	1.30815	−3.1448	0.16942	2.4471
496	−0.02617	0.324323	1.30253	−3.0477	0.17152	2.4470
497	−0.05728	0.322482	1.29962	−3.0965	0.16822	2.4525
498	−0.02415	0.322961	1.29579	−3.0571	0.17010	2.4560
499	−0.03048	0.323512	1.29175	−3.0599	0.17211	2.4594
500	−0.06572	0.321665	1.28344	−3.0935	0.16906	2.4541

Table 2 (Continued)
Transfer matrix elements for beam line 2A

Energy (MeV)	Horizontal transfer matrix elements					
	R_{11} (cm/cm)	R_{12} (cm/mr)	R_{16} (cm/%)	R_{21} (mr/cm)	R_{22} (mr/mr)	R_{26} (mr/%)
501	−0.02895	0.322477	1.28355	−3.0487	0.17157	2.4652
502	−0.03100	0.323274	1.27943	−3.0518	0.17408	2.4682
503	−0.06521	0.321268	1.27514	−3.0944	0.17059	2.4705
504	−0.05188	0.320983	1.26301	−3.0435	0.17080	2.4563
505	−0.03965	0.322162	1.26652	−3.0380	0.17414	2.4763
506	−0.04184	0.321020	1.26233	−3.0857	0.17303	2.4798
507	−0.05872	0.320015	1.25807	−3.0366	0.17175	2.4825
508	−0.08084	0.319339	1.23957	−3.0394	0.17122	2.4554
509	−0.05304	0.319617	1.24952	−3.0836	0.17276	2.4888
510	−0.06084	0.319932	1.24010	−3.0257	0.17443	2.4822

Table 2 (Continued)
Transfer matrix elements for beam line 2A

Energy (MeV)	Vertical transfer matrix elements			
	R_{33} (cm/cm)	R_{34} (cm/mr)	R_{43} (mr/cm)	R_{44} (mr/mr)
470	1.13384	0.622629	0.4786	1.14480
471	1.13350	0.622692	0.4798	1.14582
472	1.13385	0.622872	0.4826	1.14707
473	1.13271	0.622784	0.4816	1.14763
474	1.13106	0.619960	0.4832	1.14898
475	1.12979	0.619843	0.4816	1.14937
476	1.12954	0.619895	0.4825	1.15011
477	1.12885	0.619861	0.4821	1.15057
478	1.12752	0.619721	0.4801	1.15077
479	1.12706	0.619724	0.4801	1.15124
480	1.12664	0.619845	0.4820	1.15277
481	1.12510	0.619659	0.4791	1.15268
482	1.12426	0.619583	0.4778	1.15281
483	1.12378	0.619569	0.4774	1.15305
484	1.12225	0.619381	0.4743	1.15284
485	1.12121	0.619273	0.4723	1.15276
486	1.11973	0.616431	0.4731	1.15351
487	1.11812	0.616255	0.4697	1.15322
488	1.11726	0.616142	0.4678	1.15301
489	1.11681	0.616097	0.4669	1.15295
490	1.11565	0.615927	0.4641	1.15254
491	1.11498	0.615824	0.4623	1.15223
492	1.11429	0.615832	0.4623	1.15292
493	1.11395	0.615779	0.4613	1.15268
494	1.11310	0.615637	0.4589	1.15218
495	1.11224	0.615488	0.4564	1.15163
496	1.11181	0.615398	0.4548	1.15118
497	1.11137	0.615300	0.4531	1.15066
498	1.11065	0.615151	0.4507	1.14998
499	1.10912	0.612190	0.4498	1.14989
500	1.10838	0.612024	0.4471	1.14908

Table 2 (Continued)
Transfer matrix elements for beam line 2A

Energy (MeV)	Vertical transfer matrix elements			
	R_{33} (cm/cm)	R_{34} (cm/mr)	R_{43} (mr/cm)	R_{44} (mr/mr)
501	1.10815	0.611940	0.4456	1.14846
502	1.10770	0.611812	0.4434	1.14767
503	1.10710	0.611659	0.4408	1.14682
504	1.10663	0.611520	0.4385	1.14595
505	1.10676	0.611576	0.4391	1.14617
506	1.10600	0.611372	0.4356	1.14495
507	1.10542	0.611209	0.4327	1.14386
508	1.10489	0.611009	0.4296	1.14266
509	1.10461	0.610834	0.4270	1.14144
510	1.10405	0.610608	0.4236	1.14005

Table 3

Comparison of the calculated and fitted combination magnet fields

Energy (MeV)	B (kG) Ref[1]	B (kG) (Linear fit)	(Quadratic fit)	(Cubic fit)
470	3.24704	3.23676	3.22420	3.25201
471	3.09329	3.08691	3.07623	3.09576
472	2.94113	2.93706	2.92817	2.94049
473	2.78680	2.78720	2.78000	2.78595
474	2.63448	2.63735	2.63175	2.63257
475	2.48425	2.48750	2.48339	2.47992
476	2.33002	2.33764	2.33494	2.32788
477	2.17732	2.18779	2.18640	2.17651
478	2.02744	2.03793	2.03775	2.02600
479	1.87581	1.88808	1.88901	1.87567
480	1.72584	1.73823	1.74017	1.72620
481	1.57662	1.58838	1.59124	1.57703
482	1.42645	1.43852	1.44221	1.42810
483	1.27745	1.28867	1.29308	1.28003
484	1.13126	1.13882	1.14386	1.13220
485	0.98253	0.98896	0.99454	0.98413
486	0.83537	0.83910	0.84512	0.83667
487	0.68998	0.68925	0.69561	0.68896
488	0.54102	0.53940	0.54599	0.54163
489	0.39516	0.38955	0.39629	0.39404
490	0.24779	0.23969	0.24648	0.24658
491	0.09830	0.08984	0.09658	0.09912
492	−0.04883	−0.06001	−0.05342	−0.04871
493	−0.19727	−0.20986	−0.20351	−0.19641
494	−0.34632	−0.35972	−0.35371	−0.34460
495	−0.49428	−0.50957	−0.50399	−0.49304
496	−0.64355	−0.65942	−0.65438	−0.64197
497	−0.79346	−0.80927	−0.80486	−0.79150
498	−0.94312	−0.95913	−0.95544	−0.94141
499	−1.09280	−1.10898	−1.10612	−1.09180
500	−1.24456	−1.25884	−1.25689	−1.24268

Table 3 (Continued)

Comparison of the calculated and fitted combination magnet fields

Energy (MeV)	B (kG) Ref[1]	B (kG) (Linear fit)	(Quadratic fit)	(Cubic fit)
501	−1.39349	−1.40870	−1.40776	−1.39429
502	−1.54458	−1.55855	−1.55873	−1.54651
503	−1.69744	−1.70840	−1.70979	−1.69983
504	−1.85137	−1.85825	−1.86095	−1.85352
505	−2.00631	−2.00811	−2.01221	−2.00830
506	−2.16272	−2.15796	−2.16356	−2.16394
507	−2.31634	−2.30782	−2.31501	−2.32056
508	−2.47797	−2.45766	−2.46655	−2.47852
509	−2.63902	−2.60752	−2.61820	−2.63733
510	−2.80377	−2.75737	−2.76994	−2.79736

Table 4

Measured extraction energies and R, L and z values

Energy MeV	R (in.)	L (in.)	z (in.)
472	101.926	2.299	1.500
480	100.629	3.399	1.500
485	99.750	3.672	1.629
500	97.185	4.349	1.449
510	95.338	4.349	1.167

Table 5

Measured combination magnet field as a function of current

Raw data		Useful range	
I (A)	Field (kG)	I (A)	Field (kG)
50	0.954	50	0.954
100	1.938	100	1.938
150	2.913	150	2.913
200	3.888	200	3.888
250	4.841	200	3.914
300	5.789	100	1.963
350	6.715		
400	7.612		
450	8.427		
500	9.146		
400	7.674		
300	5.824		
200	3.914		
100	1.963		

Table 6

Fitted values to the raw data for the 2A combination magnet field

I (A)	B_{meas} (kG)	Type of fit: Linear	Quadratic	Cubic
50	0.954	1.07702	0.91060	0.97734
100	1.938	2.00351	1.94419	1.93358
150	2.913	2.92999	2.95049	2.90930
200	3.884	3.85648	3.92949	3.89115
250	4.841	4.78297	4.88119	4.86576
300	5.789	5.70946	5.80560	5.81979
350	6.715	6.63594	6.70272	6.73986
400	7.612	7.56243	7.57254	7.61262
450	8.427	8.48892	8.41506	8.42471
500	9.146	9.41540	9.23029	9.16277
400	7.674	7.56243	7.57254	7.61262
300	5.824	5.70946	5.80560	5.81979
200	3.914	3.85648	3.92949	3.89115
100	1.963	2.00351	1.94419	1.93358

Table 7

Fitted values to the useful data for the 2A combination magnet field

I (A)	B_{meas} (kG)	Type of fit: Linear	Quadratic	Cubic
50	0.954	0.96305	0.95783	0.9540
100	1.938	1.94182	1.94475	1.9505
150	2.913	2.92059	2.92450	2.9130
200	3.884	3.89936	3.89708	3.8990
200	3.914	3.89936	3.89708	3.8990
100	1.963	1.94182	1.94475	1.9505

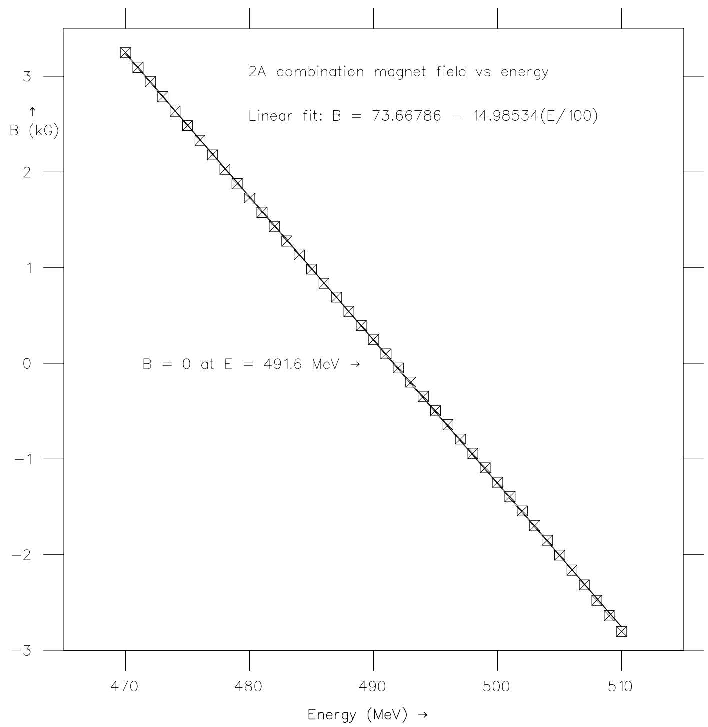

Fig. 1. Linear fit to 2A combination magnet field.

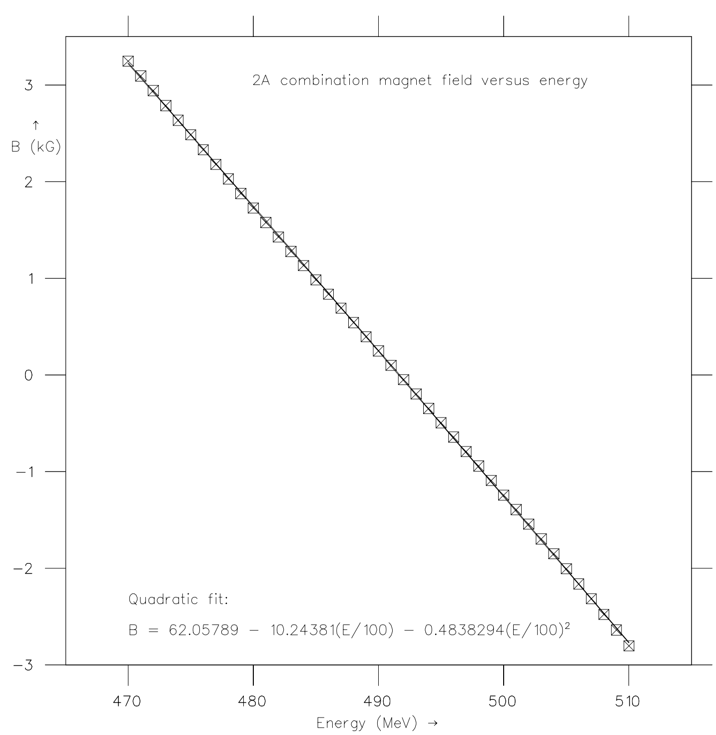

Fig. 2. Quadratic fit to 2A combination magnet field.

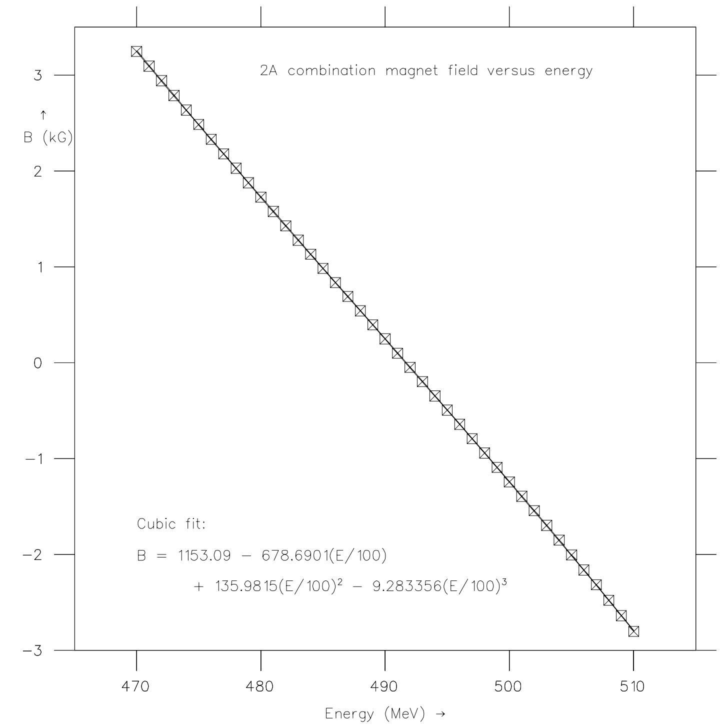

Fig. 3. Cubic fit to 2A combination magnet field.

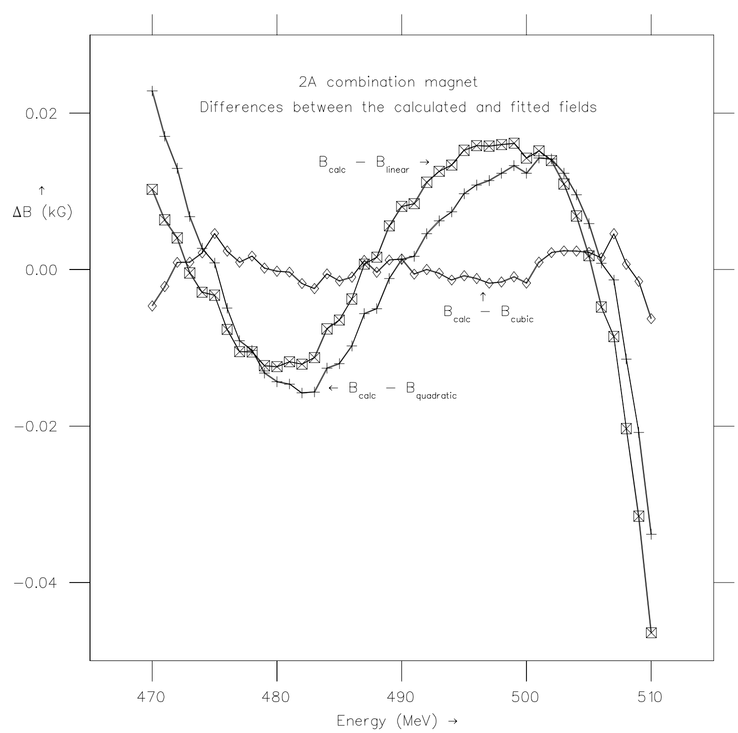

Fig. 4. Difference between calculated and fitted fields for 2A combination magnet.

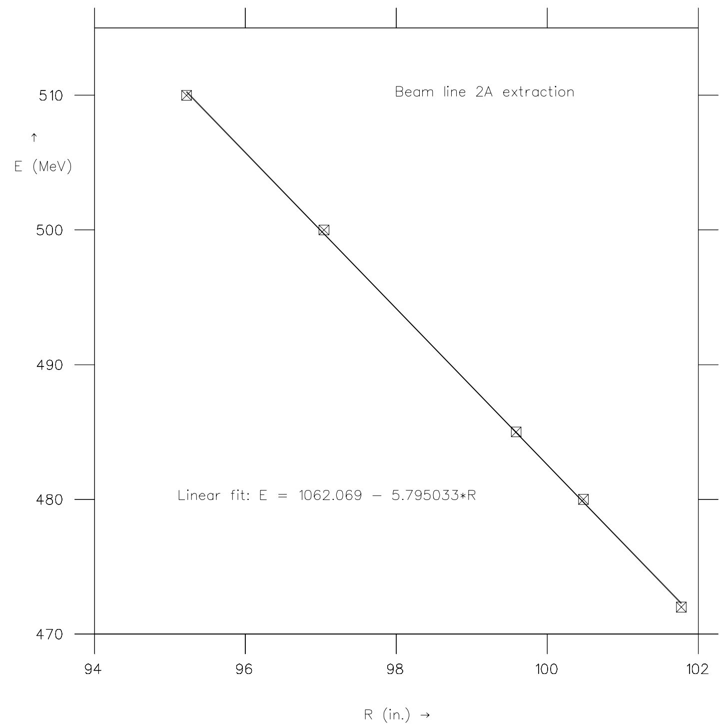

Fig. 5. Experimental values of energy versus R of the extraction mechanism.

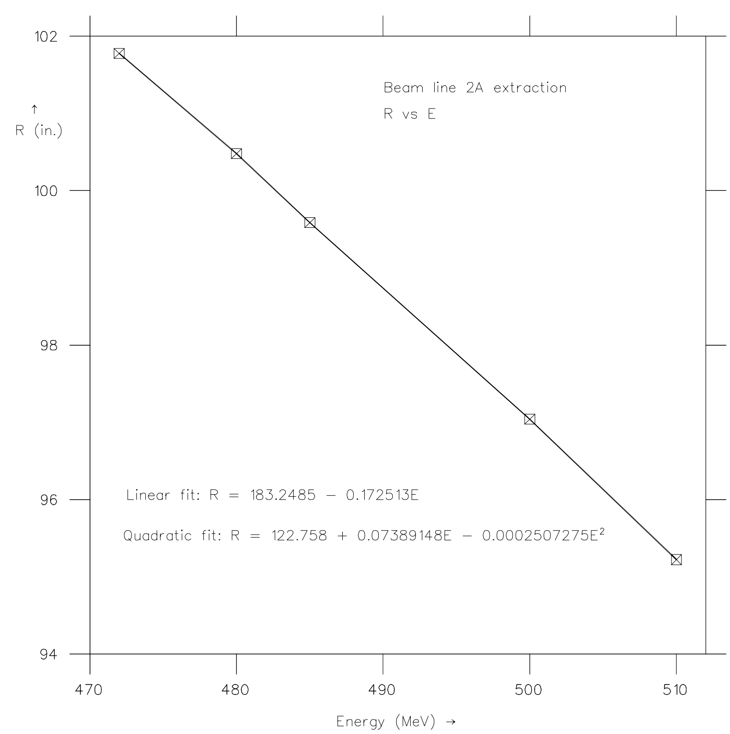

Fig. 6. Experimental values of R of the extraction mechanism versus energy.

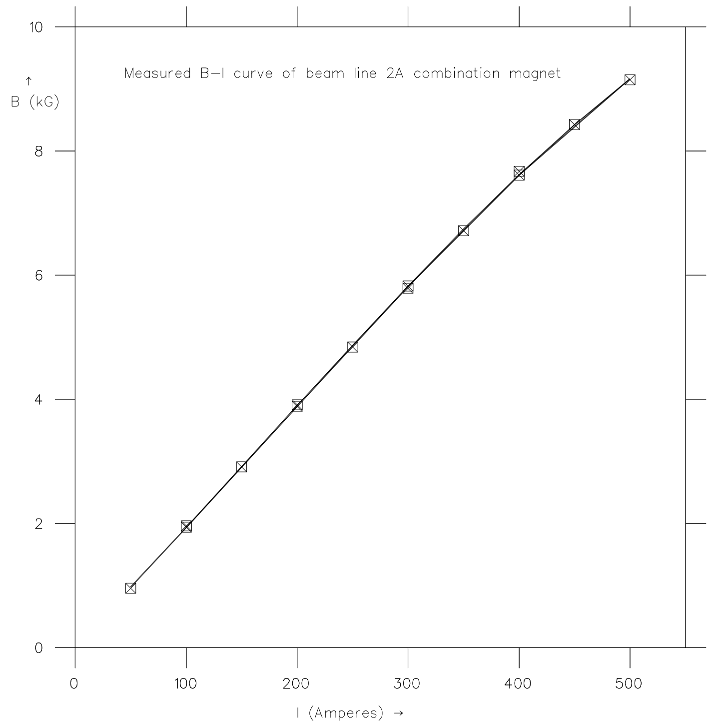

Fig. 7. Plot of the raw B–I measured data of the 2A combination magnet.

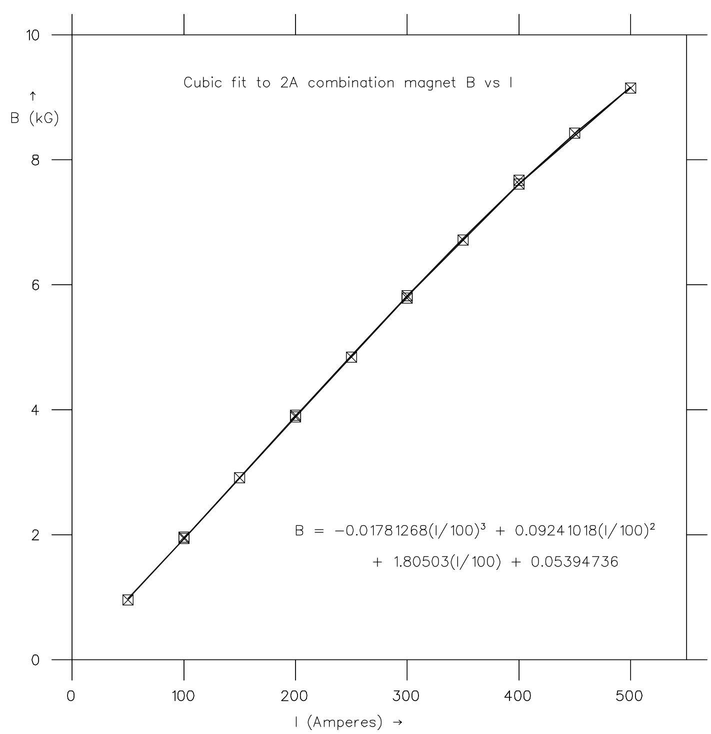

Fig. 8. Cubic fit to the raw B–I measured data of the 2A combination magnet.

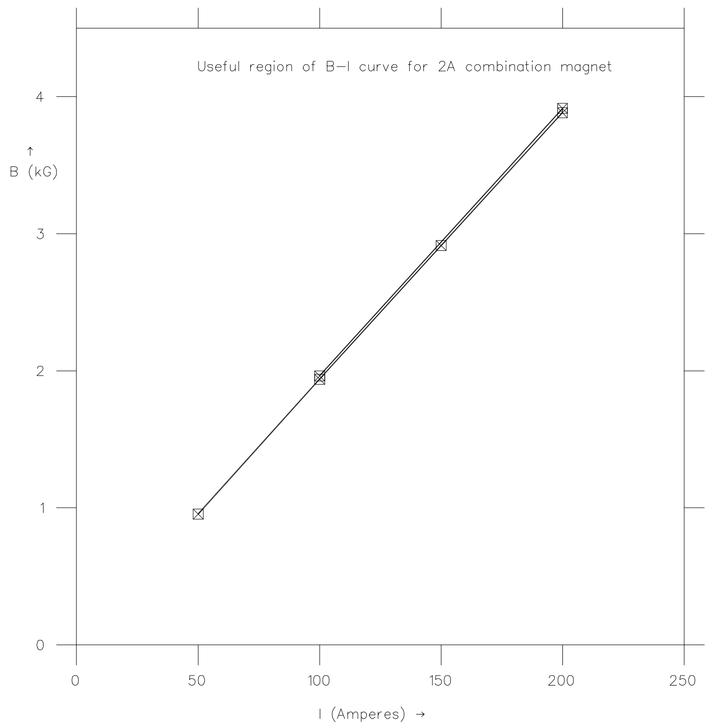

Fig. 9. Plot of the useful range of B–I measured data of the 2A combination magnet.

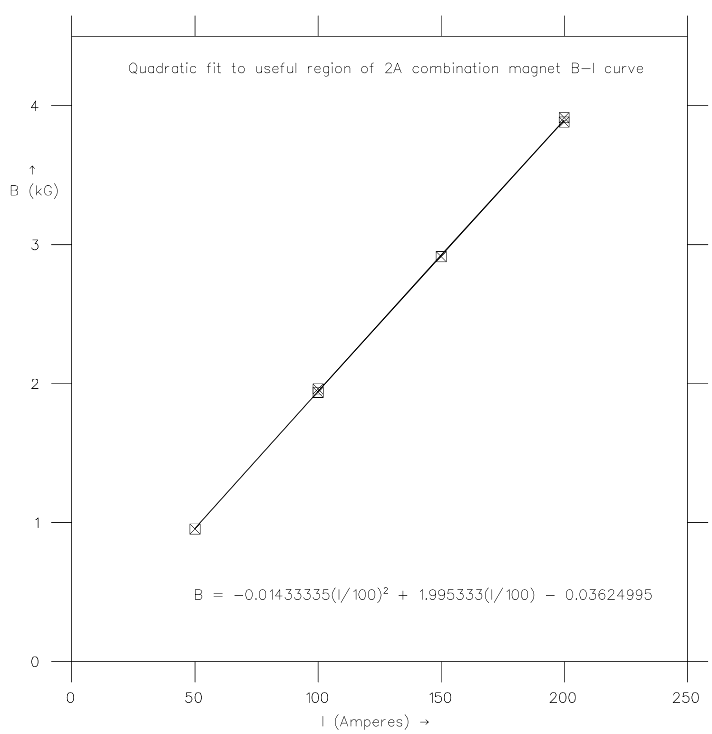

Fig. 10. Quadratic fit to the useful range of B–I measured data of the 2A combination magnet.