Configuration and calibration of the BigBite spectrometer

Miha Mihovilovič
For the E05-102 Collaboration

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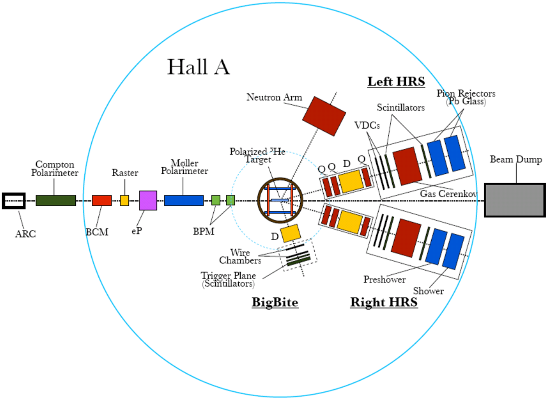
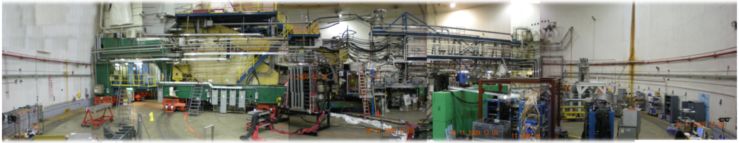
Jefferson Lab

BIGBITE
A Jefferson Lab Large Acceptance Spectrometer

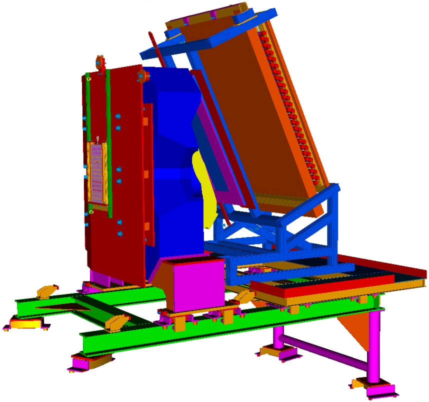
E05-102 Experimental Setup





BigBite Spectrometer
General Description

BigBite characteristics	
Configuration	Dipole
Momentum range	$(200 - 900)\ \frac{\mathrm{MeV}}{\mathrm{c}}$
Momentum acceptance	$-0.6 \leq \frac{\delta p}{p} \leq 0.8$
Momentum resolution	4×10^{-3}
Angular acceptance	$100\ \mathrm{msr}$
Angular resolution	$\approx 1\ \mathrm{mr}$
Flight path (during $(e, e'd)$)	$\approx 3\ \mathrm{m}$
Maximum Field	$0.92\ \mathrm{T}$



BigBite Hadron detector package

1. Two MWDCs for tracking, each consisting of 6 wire planes u,u',v,v',x,x'
2. Two Scintillation planes E/dE for particle Identification & Energy determination

The main purpose of the optics calibration is to determine the target variables $(y_{Tg}, \phi_{Tg}, \theta_{Tg}, \delta_{Tg})$ from the focal plane variables $(x_{Fp}, \theta_{Fp}, y_{Fp}, \phi_{Fp})$. There are many different ways to do that:

1. Analytical Approximations
   - `THaOpticsAnalytical`, `THaVertexTime` - Circular-arc approximation
   - `THaOpticsAGen` - Effective-midplane approximation
2. Transport matrix formalism
   - `THaOpticsHRS`

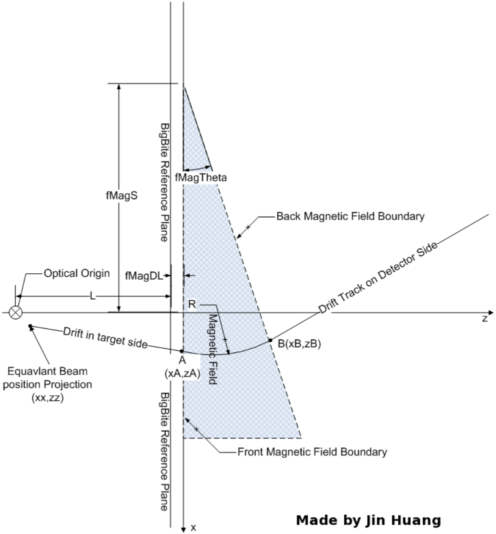
$$\begin{pmatrix} \delta_{Tg} \\ \theta_{Tg} \\ y_{Tg} \\ \phi_{Tg} \end{pmatrix} = \begin{pmatrix} \langle \delta_{Tg} | x_{Fp} \rangle & \langle \delta_{Tg} | \theta_{Fp} \rangle & \cdots & \cdots \\ \langle \theta_{Tg} | x_{Fp} \rangle & \langle \theta_{Tg} | \theta_{Fp} \rangle & \cdots & \cdots \\ \cdots & \cdots & \langle y_{Tg} | y_{Fp} \rangle & \langle y_{Tg} | \phi_{Fp} \rangle \\ \cdots & \cdots & \langle \phi_{Tg} | y_{Fp} \rangle & \langle \phi_{Tg} | \phi_{Fp} \rangle \end{pmatrix} \begin{pmatrix} x_{Fp} \\ \theta_{Fp} \\ y_{Fp} \\ \phi_{Fp} \end{pmatrix} + \cdots$$

Pros

- Very simple
- Few parameters
- Momentum resolution $\approx 2-4\%$

Cons

- Ignores fringe fields
- Need exact values of the parameters
- There is more than one solution
- Always some tweaking needed



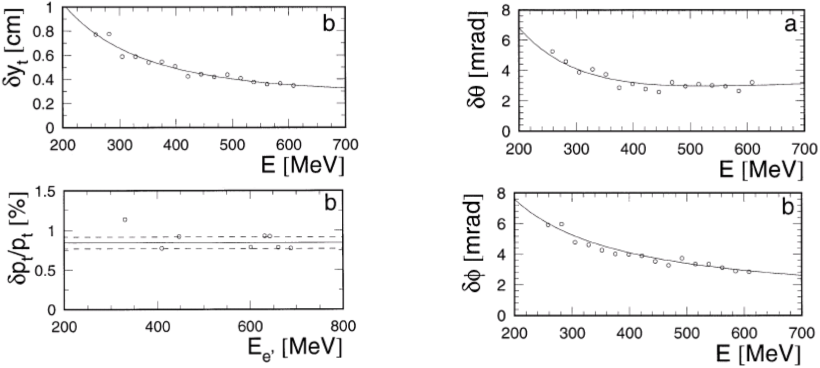
Made by Jin Huang

1. Various parametrization of the matrix are possible. Here polynomial expansion is considered:

$$\Omega_{Tg} = \sum_{i,j,k} \theta_{Fp}^{i} y_{Fp}^{j} \phi_{Fp}^{k} \sum_{l=0}^{7} a_{ijkl}^{\Omega_{Tg}} x_{Fp}^{l}\,, \quad \Omega_{Tg} = (\delta_{Tg}, \theta_{Tg}, \phi_{Tg}, y_{Tg})$$

2. Same matrix form as for the High Resolution Spectrometers. Ability to use the same code.
3. Easy to calculate with.
4. Higher-order terms can cause bogus oscillations of the target variables. High-order matrix terms must be well under control.
5. Calibration might not work beyond the limits set by the calibration points. Wild oscillations possible.

Ambition to get as close as possible to BigBite resolution from NIKHEF.



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NIKHEF

y_{Tg} Calibration

- Quasi-Elastic ^{12}C runs used with no sieve-slit
- Only coincidence events considered

ϕ_{Tg} & θ_{Tg} Calibration

- Quasi-Elastic ^{12}C data with sieve slit
- Hydrogen (deuteron) elastic data used for absolute calibration and offset correction

δ_{Tg} Calibration

- Calibration with Missing-Mass peak reconstruction using Quasi-Elastic ^{2}H data.
- Calibration with q-vector reconstruction for elastic runs using elastic ^{1}H and ^{2}H data with BigBite set to different momenta

Chronology y_{Tg} reconstruction

0th Step

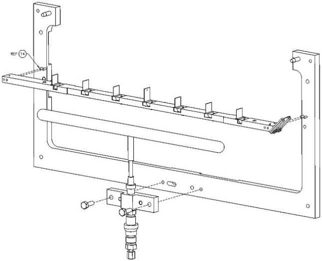
- Analytical approach to get a rough estimate of matrix elements

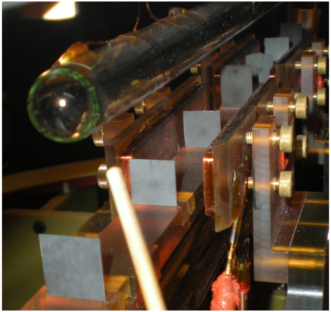
1st Attempt

- Manual approach to determine low order matrix elements
- Not useful for final analysis
- Low order matrix elements are robust - used to check more sophisticated methods

Final Approach

- Final determination of matrix elements for further physical analysis





y_{Tg} reconstruction - Final Approach

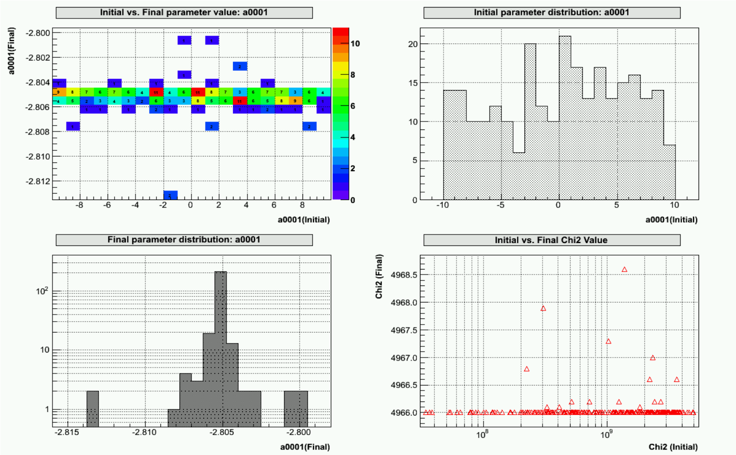
1. Up to 5^{th} order matrix elements are considered.
2. Started with 70 matrix elements, ended with 25
3. Relevant matrix elements chosen using a combination of a Monte Carlo simulation of BigBite optics and manual selection.
4. The determined set of the matrix elements is not unique. Other combinations of matrix elements could be used.
5. For calculation of matrix elements a χ^2-minimization was used

$$\chi^2\left(a_i^{Tg}\right) = \sqrt{\left(y_{\mathrm{Tg}}^{\mathrm{True}} - y_{\mathrm{Tg}}^{\mathrm{Optics}}\left(x_{Fp}, y_{Fp}, \theta_{Fp}, \phi_{Fp}; a_i^{y_{Tg}}\right)\right)^2}$$

6. Due to the numerical complexity of the minimization it is not certain that the solution is unique.

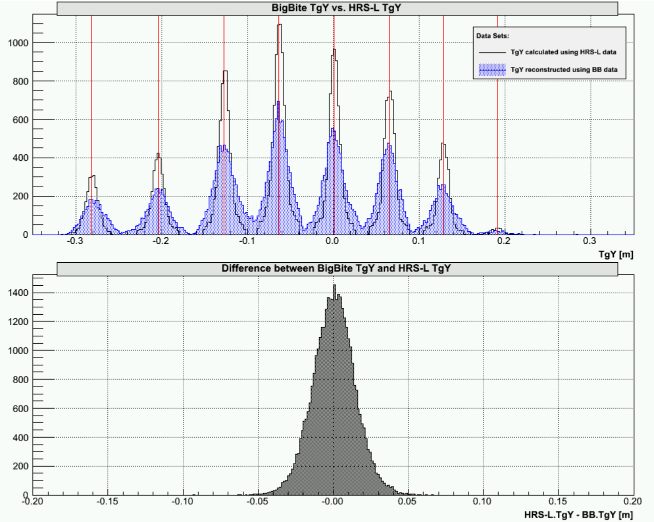
Robustness of the method

The robustness of the method is tested by checking the convergence of the minimization for a large number of randomly chosen initial sets of parameters.



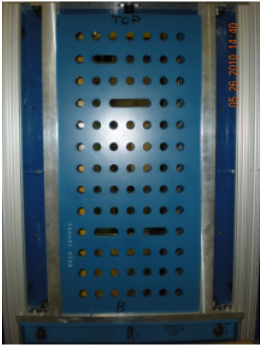
y_{Tg} reconstruction - Final Approach: Results

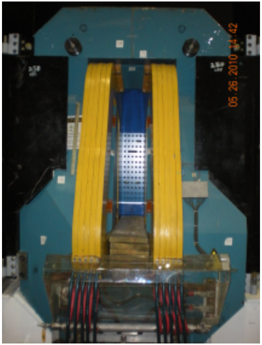
- $^{12}C(e,e'p)$ run #3491 with 7-foil target: $\sigma_{TgY} \approx 0.96\,\mathrm{cm}$

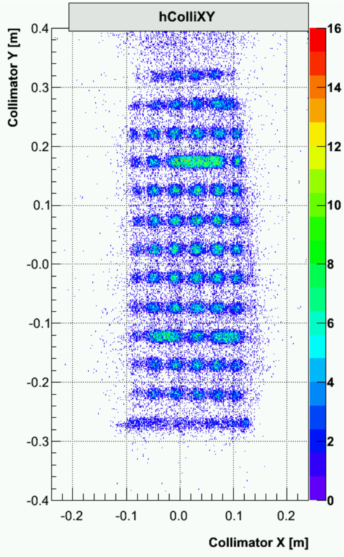


θ_{Tg} and ϕ_{Tg} Calibration
Results

- For calibration a $3.5\,\mathrm{cm}$-thick sieve slit collimator was used
- Most of the holes visible, some are out of the acceptance (obstructed by target Helmholtz coils)

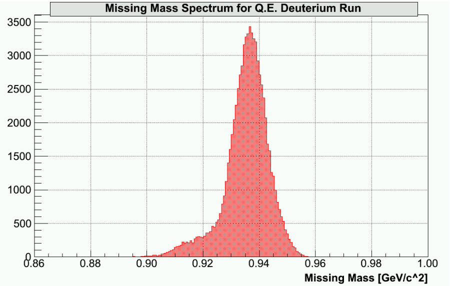


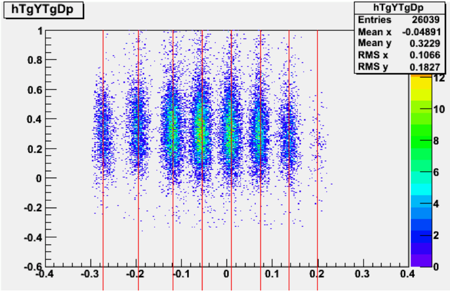




δ_{Tg} reconstruction
results

- δ_{Tg} is being determined using elastic H_2 and quasi-elastic D_2 data, by minimization of the width of the missing-mass peak.
- Current missing-mass resolution : $\sigma_{\delta_{Tg}} \lesssim 6\,\mathrm{MeV/c^2}$.





Conclusion and Outlook

Conclusions

- Analytical model not very promising.
- Transport matrix gives better results. High-order terms must be well under control.
- Prefer matrix with low-order terms.
- We already have good results. Hoping for even better ones.

To-Do

- Determine better matrix elements for ϕ_{Tg} and δ_{Tg}.
- Reduce number of matrix elements for ϕ_{Tg} from 69 to ≈ 30.
- Try to reduce number of matrix elements for other variables.
- Do all the necessary tests and check robustness of the method.
- Maybe try to make analytical model work.

Collaborator List for the Quasi-Elastic Family of Experiments (E05-0015, E05-102, E08-005)

Spokespersons:

T. Averett
J. P. Chen
S. Gilad
D. Higinbotham
X. Jiang
W. Korsch
B. E. Norum
S. Širca
V. Sulkosky

Graduate Students:

G. Jin
E. Long
M. Mihovilovič
Y. Zhang

Run Coordinators:

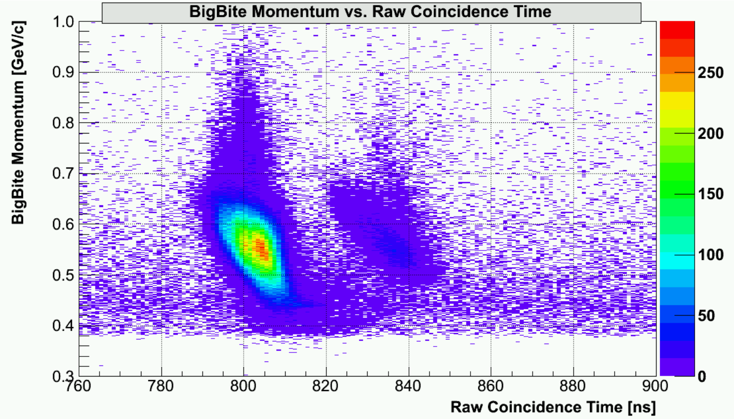
A. Camsonne
P. Monaghan
S. Riordan
B. Sawatzky
R. Subedi
V. Sulkosky
Y. Qiang
B. Zhao

Collaboration:

K. Allada
B. Anderson
J. R. M. Annand
W. Boeglin
P. Bradshaw
M. Canan
C. Chen
R. De Leo
X. Deng
A. Deur
C. Dutta
L. El Fassi
D. Flay
F. Garibaldi
H. Gao
R. Gilman
S. Golge
O. Hansen
T. Holmstrom
J. Huang
H. Ibrahim
E. Jensen
M. Jones
H. Kang
J. Katich
C. W. Kees
P. King
J. LeRose
R. Lindgren
H. Lu
W. Luo
P. Markowitz
M. Meziane
R. Michaels
B. Moffit
N. Muangma
H. P. Khanal
K. Pan
D. Parno
E. Piasetzky
P. Pradshaw
M. Posik
A. J. R. Puckett
X. Qian
X. Qui
A. Saha
F. Salvatore
M. Shabestari
A. Shahinyan
B. Shoenrock
J. St. John
A. Tobias
W. Tireman
G. M. Urciuoli
D. Wang
K. Wang
J. Watson
B. Wojtsekhowski
Z. Ye
X. Zhan
X. Zheng
L. Zhu

- Good optics helps us distinguish between protons and deuterons.

$^{2}H(e,e'p)$ Calibration run #2164, $E_{beam} = 2\,\mathrm{GeV}$



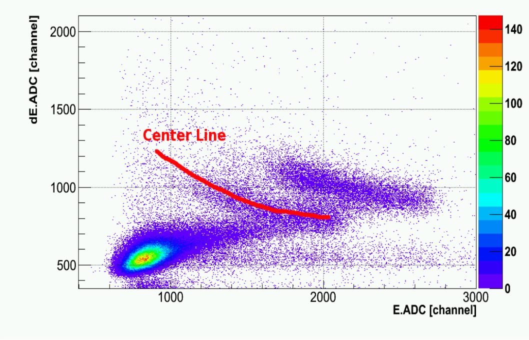
Deuteron Selection

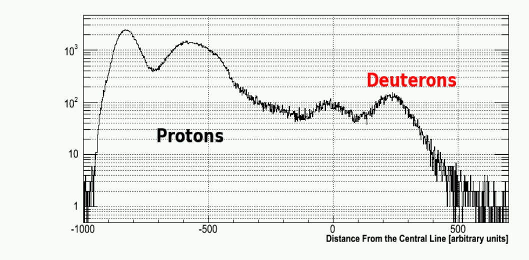
- For the calibration 1^{st}- and 2^{nd}-pass H runs and 2^{nd}-pass ^2H runs at different $p^{BB}_{central}$ $(0.37\,\mathrm{GeV/c})$ and $0.5\,\mathrm{GeV/c})$ were used. For these runs $\vec{q} = \vec{p}^{BB}_{proton}$.

Problem

How to separate deuterons from protons in ^2H runs?

- Cuts on the dE/E plots: Calculating distance from the main band and selecting the events on the positive side.





y_{Tg} reconstruction - 1st Attempt

Matrix elements were determined by a semi-automatic method. Various scatter plots were used to determine how target variables depend on the focal-plane variables. Only two-variable dependencies were considered.

Step No.1

First determine how y_{Tg} depends on ϕ_{Fp} for different values of y_{Fp}. For each narrow cut on y_{Fp} we can find:

$$y_{Tg}(\phi_{Fp}) \quad = \quad c_1(y_{Fp})\phi_{Fp} + c_0(y_{Fp})$$

Step No.2

Determine how c_i depend on y_{Fp}:

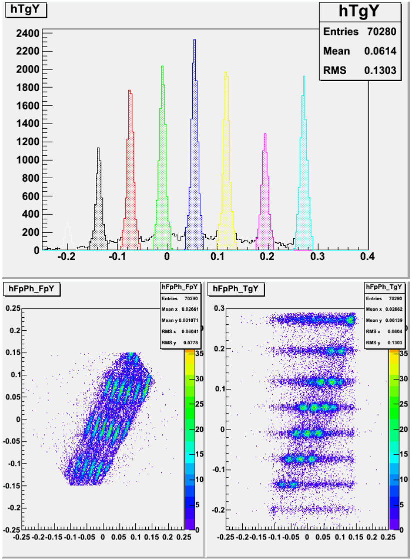
$$c_i(y_{Fp}) = d_{i2}\, y_{Fp}^2 + d_{i1}\, yFp + d_{i3}$$

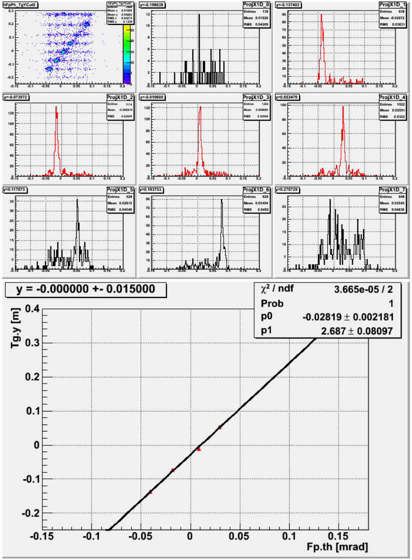
Results

Parameters d_{ij} are matrix elements for y_{Tg}.

y_{Tg} reconstruction - 1st Attempt

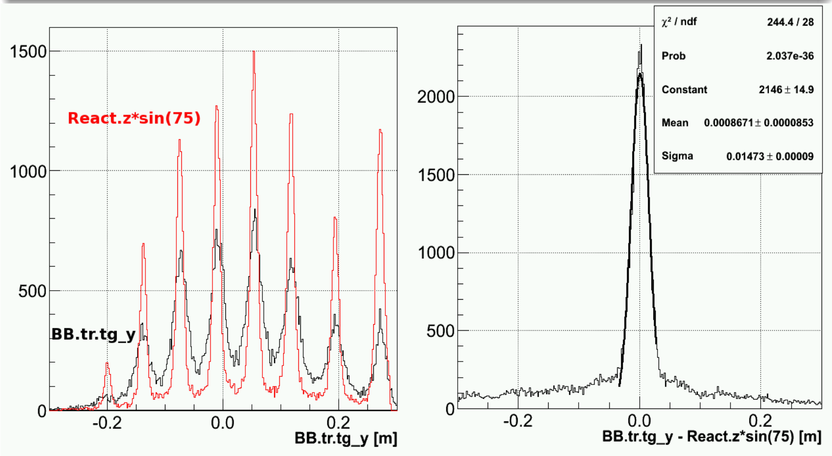
Demonstration





y_{Tg} reconstruction - 1st Attempt: Results

- $^{12}C(e,e'p)$ run #3491 with 7-foil target: $\sigma_{TgY} \approx 1.2\,\mathrm{cm}$



- ADC signals from the dE and E planes can be used for particle ID as well as for the estimation of the particle momentum using the Bethe-Bloch equation:

$$\left(\frac{dE}{ds}\right)_{Bethe-Bloch} \propto \frac{Zz^2}{A}\rho\frac{1}{\beta^2}[1+\cdots]$$

- Since plastic scintillators are used, Birks formula needs to be considered for the Light output of the scintillators:

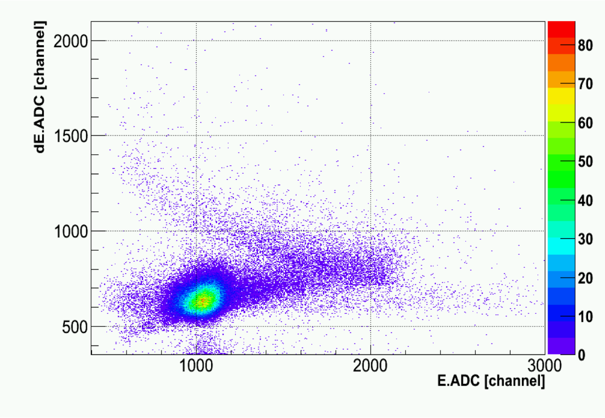
$$\left(\frac{dL}{ds}\right)_{Mean} = A\frac{\left(\frac{dE}{ds}\right)}{1+k_{Birks}\left(\frac{dE}{ds}\right)}$$

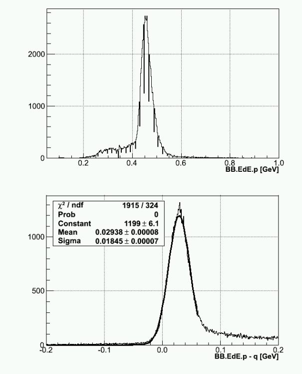
- Adjusting A_{dE}, A_E and k_{Birks} we can fit a theoretical curve to our data. In this way we can estimate the momentum of the events at different regions of the dE/E plots.

Exact calculations of momenta is impossible due to straggling, path-length distribution, etc.

dE/E as alternative momentum reconstruction
A good example

- Elastic Hydrogen run #3488 at $E_b = 2\,\mathrm{GeV}$, $p_p \approx 450\,\frac{\mathrm{MeV}}{\mathrm{c}}$:

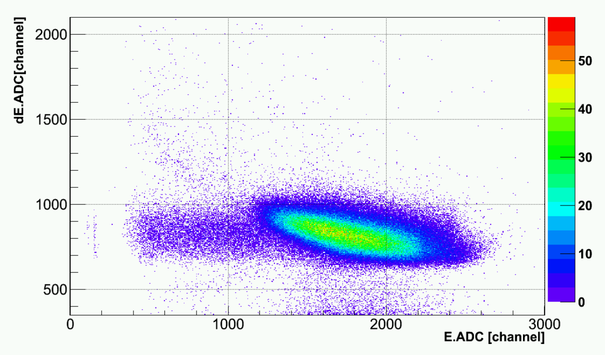


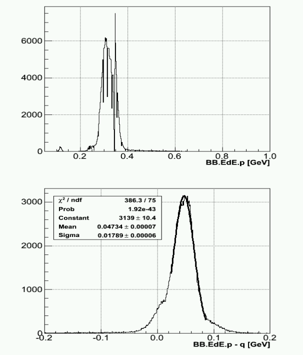


As a rough approximation,the method works reasonably well for this example: $\frac{\vec{p}-\vec{q}}{q} \approx +7\,\%$, $\quad \sigma_{\vec{p}-\vec{q}} \approx 19\,\frac{\mathrm{MeV}}{\mathrm{c}}$

dE/E as alternative momentum reconstruction
A bad example

- Elastic Hydrogen run #1518 at $E_b = 1\,\mathrm{GeV}$, $p_p \approx 340\,\frac{\mathrm{MeV}}{\mathrm{c}}$:





Problem

Near the punch-through point all points correspond to the same mean energy-loss i.e. to the same momentum. Consequently an artificial sharp peak appears at the P.T.P.