BigBite Optics

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For the E05-102 Collaboration

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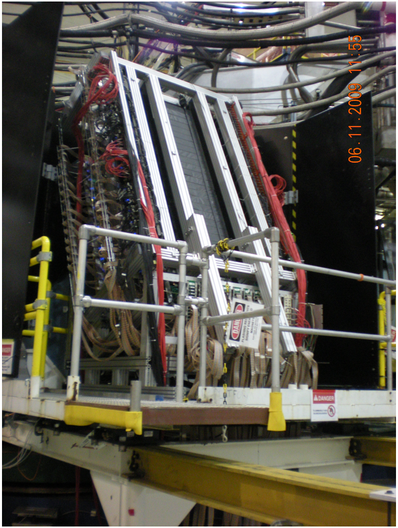
BigBite characteristics	
Configuration	Dipole
Momentum range	$200 - 900\ \frac{\mathrm{MeV}}{\mathrm{c}}$
Momentum acceptance	$-0.6 \leq \frac{\delta p}{p} \leq 0.8$
Momentum resolution	4×10^{-3}
Angular acceptance	$\approx 100\ \mathrm{msr}$
Angular resolution	$\approx 1\ \mathrm{mr}$
Flight path (during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

BigBite Hadron detector package

1. Two MWDCs for tracking
2. Each MWDC consists of 6 wire planes u,u',v,v',x,x'
3. 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. Different Analytical Approximations
   - `THaOpticsAnalytical`, `THaVertexTime` - Circular arc approximation
   - `THaOpticsAGen` - Effective-midplane approximation
2. Transport matrix formalism
   - `THaOpticsHRS`

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

Analytical Model THaVertexTime

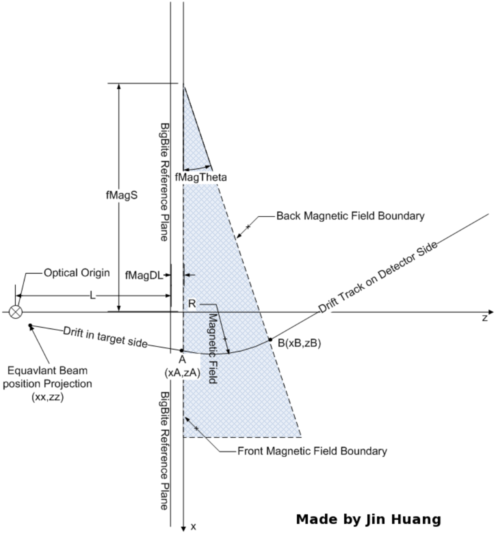
Pros & Cons

Pros

- Very simple
- Only few parameters
- Resolution is $\approx 2-4\%$

Cons

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



1. For BigBite the same matrix structure as for the HRS is being used.

$$\{\delta_{Tg}, \theta_{Tg}, \phi_{Tg}, y_{Tg}\} = \sum_{i,j,k} \theta^i_{Fp} y^j_{Fp} \phi^k_{Fp} \sum_{z=0}^{7} a_z x^z_{Fp}$$

2. Until now the 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. So far we considered only two-variable dependencies.

$$\begin{aligned} \delta_{Tg} &= \delta_{Tg}(x_{Fp}, \theta_{Fp}), \qquad \theta_{Tg} = \theta_{Tg}(x_{Fp}, \theta_{Fp}) \\ y_{Tg} &= y_{Tg}(y_{Fp}, \phi_{Fp}), \qquad \phi_{Tg} = \phi_{Tg}(y_{Fp}, \phi_{Fp}) \end{aligned}$$

3. At the moment the second iteration of the matrix element determination is being done.

Current Transport Matrix

δ_{Tg} and y_{Tg} Matrix Elements

These matrix elements work reasonably well.

ϕ_{Tg} Matrix Elements

Not determined yet. Using assumption that BigBite is an ideal dipole: ϕ_{Tg} should be equal to ϕ_{Fp}. In this approximation $\langle \phi_{Tg} | \phi_{Fp} \rangle = 1$.

θ_{Tg} Matrix Elements

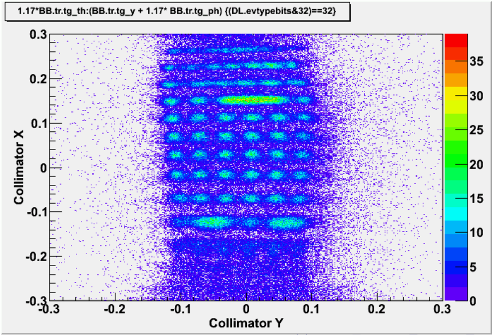
We have only poor 1^{st} order approximation for θ_{Tg}.

```
[matrix]
D 0 0 0  -0.0062   -0.9545   1.1391  0.0000
D 1 0 0   3.3909   -7.6819   7.7660  0.0000
D 2 0 0  11.7304  -19.2305  21.1691  0.0000
D 3 0 0  14.3041   -8.6769   3.5387  0.0000

T 0 0 0   0.0106   -0.4968  -0.1145  0.0000
T 1 0 0   0.4910    0.1213  -0.4243  0.0000

P 0 0 1   1.0000    0.0000   0.0000  0.0000

Y 0 0 0  -0.0321    0.0000   0.0000  0.0000
Y 0 1 0  -1.0241    0.0000   0.0000  0.0000
Y 0 2 0  -0.4919    0.0000   0.0000  0.0000
Y 0 0 1   2.8075    0.0000   0.0000  0.0000
Y 0 1 1   0.7202    0.0000   0.0000  0.0000
Y 0 2 1  -0.7153    0.0000   0.0000  0.0000
```

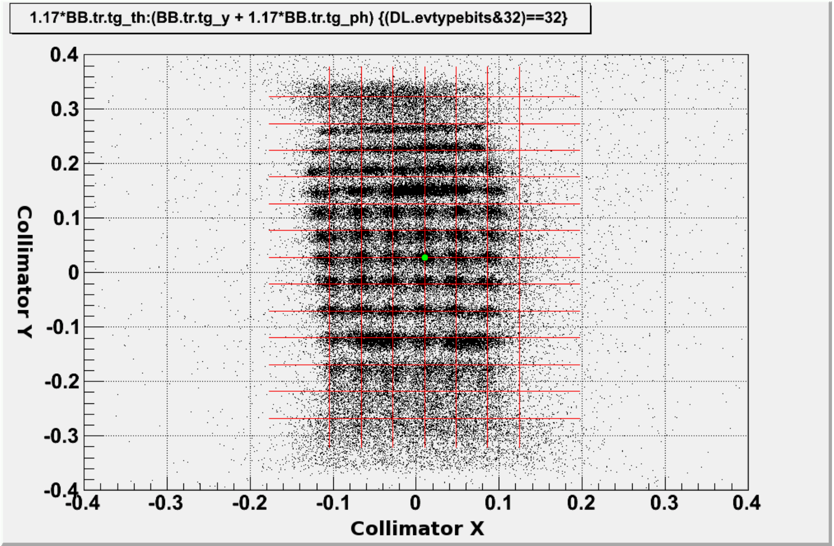
Sieve slit #1
First reconstruction

BigBite Sieve Slit

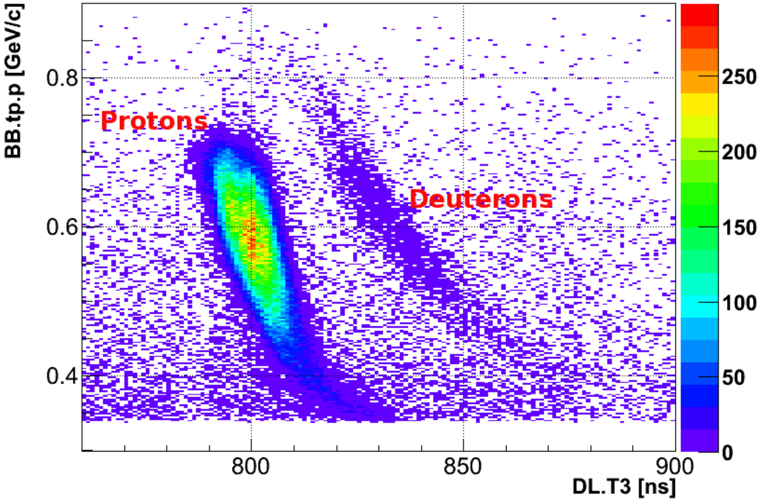
- A 3.5 cm sieve during (e,e'd)
- Most of the holes already visible
- Some are out of the acceptance (covered by Helmholtz coils)



Comparison of reconstructed hole positions with true positions

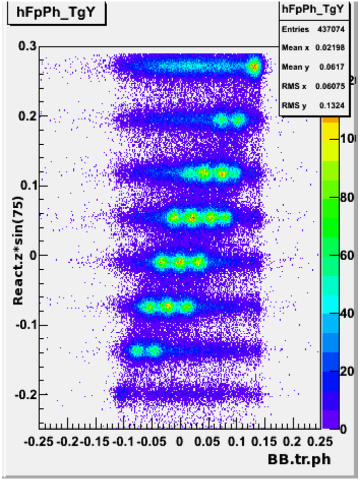


$^3\vec{He}(\vec{e}, e'd)$ Production run #2294, $E_{beam} = 2\,\mathrm{GeV}$



y_{Tg} reconstruction

Used carbon runs because with these runs we cover a larger portion of the BigBite Focal plane.



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}:

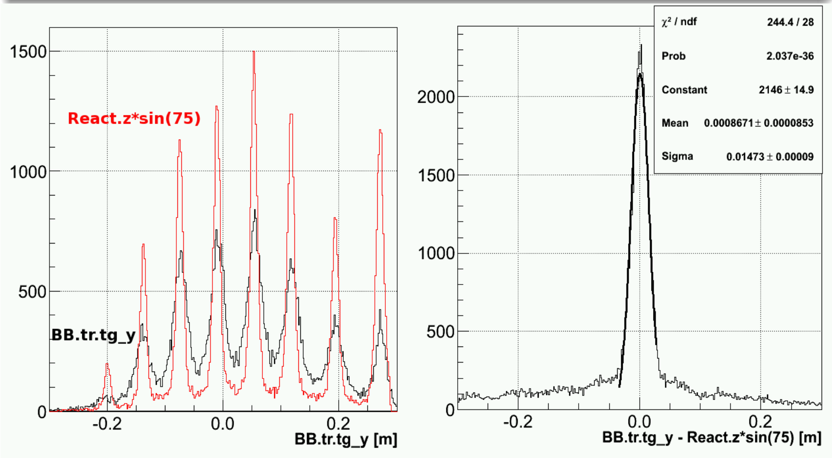
$$c_i(y_{Fp}) = d_{i2}y_{Fp}^2 + d_{i1}x_{Fp} + d_{i3}$$

Results

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

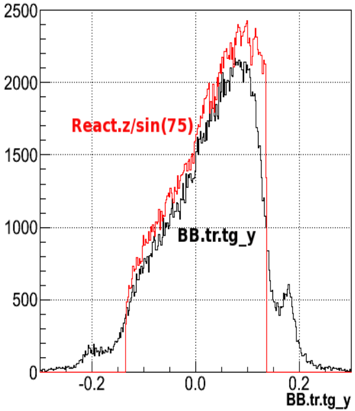
y_{Tg} reconstruction results #1

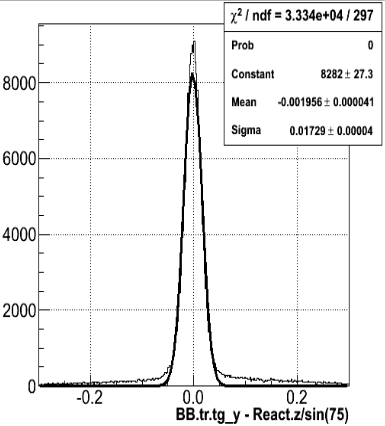
- $^{12}C(e,e'p)$ run #3491 with 7-foil target: $\sigma_{TgY} \approx 1.5\,\mathrm{cm}$



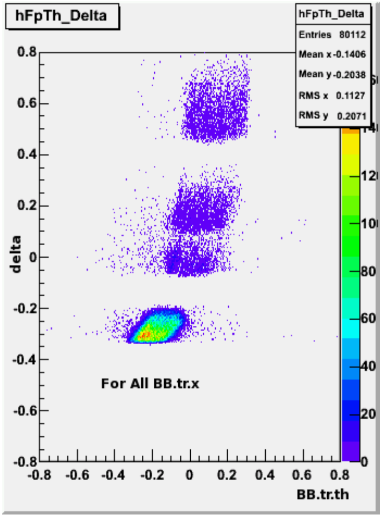
y_{Tg} reconstruction results #2

- $^3\vec{He}$ Production run #2294: $\sigma_{TgY} \approx 1.7\,\mathrm{cm}$





δ_{Tg} reconstruction



Step No.1

First determine how δ_{Tg} depends on θ_{Fp} for different values of x_{Fp}. For each narrow cut on x_{Fp} seek for a polynomial:

$$\delta_{Tg}(\theta_{Fp}) = a_3(x_{Fp})\theta_{Fp}^3 + a_2(x_{Fp})\theta_{Fp}^2 + a_1(x_{Fp})\theta_{Fp} + a_0 x_{Fp})$$

Step No.2

Determine how a_i depend on x_{Fp}:

$$a_i(x_{Fp}) = b_{i2}x_{Fp}^2 + b_{i1}x_{Fp} + b_{i3}$$

Results

Parameters b_{ij} are matrix elements for δ_{Tg}.

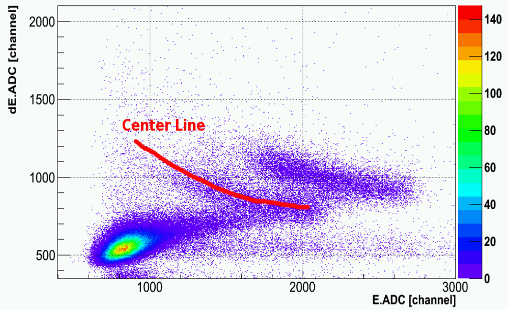
Deuteron Selection

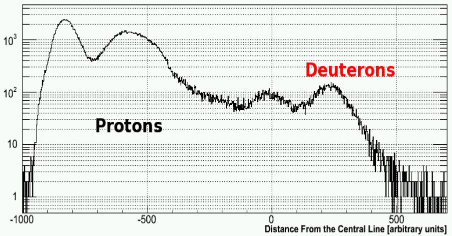
- For the calibration 1^{st}- and 2^{nd}-pass H runs and 2^{nd}-pass ^2H runs at different $p^{BB}_{central} = 0.37\,\mathrm{GeV/c}$ and $0.5\,\mathrm{GeV/c}$ were used. For these runs $\vec{q} = \vec{p}^{BB}_{proton}$.

Problem

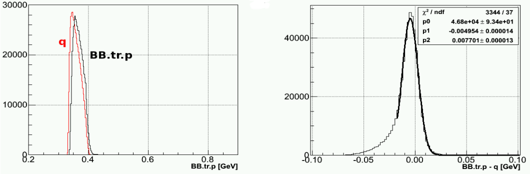
How to isolate deuterons from protons in ^2H runs?

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





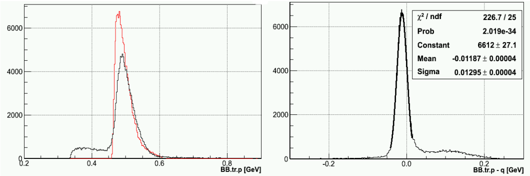
1. Elastic hydrogen run #1518 at $E_{beam} = 1\,\mathrm{GeV}$:



$\frac{\vec{p}-\vec{q}}{q} \approx -1\,\%$

$\sigma_{\vec{p}-\vec{q}} \approx 8\,\frac{\mathrm{MeV}}{\mathrm{c}}$

2. Elastic hydrogen run #3488 at $E_{beam} = 2\,\mathrm{GeV}$:



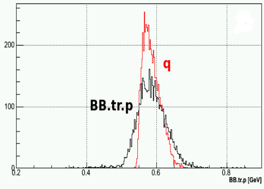
$\frac{\vec{p}-\vec{q}}{q} \approx -4\,\%$

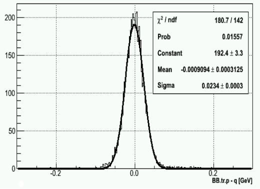
$\sigma_{\vec{p}-\vec{q}} \approx 13\,\frac{\mathrm{MeV}}{\mathrm{c}}$

Results

Matrix seem to be working reasonably well in the wide momentum region between 300 MeV/c and 600 MeV/c.

1. Elastic deuterium run #2164 at $p_{central} = 0.5\ \frac{\mathrm{GeV}}{\mathrm{c}}$:

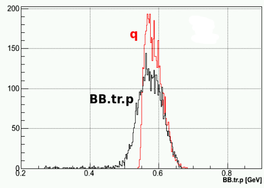


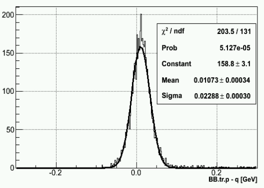


$$\frac{\vec{p}-\vec{q}}{q} \approx 0\,\%$$

$$\sigma_{\vec{p}-\vec{q}} \approx 23\ \frac{\mathrm{MeV}}{\mathrm{c}}$$

2. Elastic deuterium run #2167 at $p_{central} = 0.37\ \frac{\mathrm{GeV}}{\mathrm{c}}$:





$$\frac{\vec{p}-\vec{q}}{q} \approx +3\,\%$$

$$\sigma_{\vec{p}-\vec{q}} \approx 23\ \frac{\mathrm{MeV}}{\mathrm{c}}$$

Results

Matrix works for both momentum settings of the BigBite.

dE/E as alternative momentum reconstruction

Background

- 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:

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

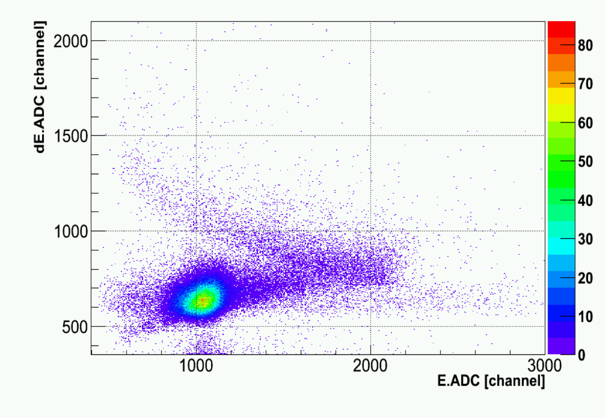
- Adjusting A_{dE}, A_E and k_{Birks} we can fit a theoretical curve to our data. In this way we can estimate the momentum of the events at different regions of the dE/E plots.

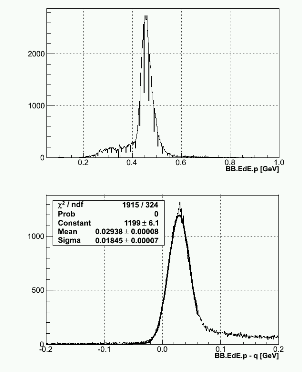
Exact calculations of momenta is impossible due to straggling, path-length distribution, etc.

dE/E as alternative momentum reconstruction

A good example

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



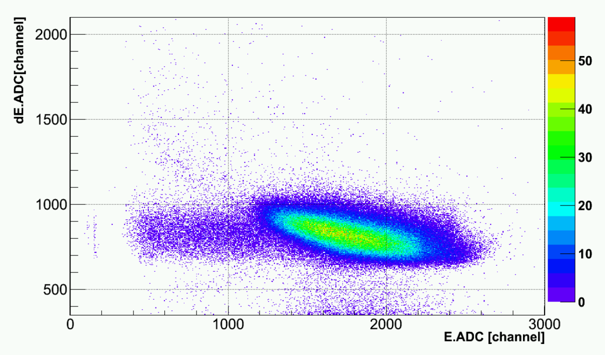


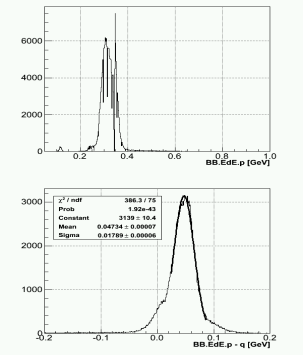
For a rough approximation,the method seems to work reasonably well for this example: $\frac{\vec{p}-\vec{q}}{q} \approx +7\,\%$, $\quad \sigma_{\vec{p}-\vec{q}} \approx 19\,\frac{\mathrm{MeV}}{\mathrm{c}}$

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.

Conclusion and Outlook

Conclusions

- Problems with Analytical model - Work in progress.
- First attempts to determine the matrix elements look promising.
- We can already see a sieve slit.
- Resolution is not yet good enough.

To-Do

- Try to make analytical model work.
- Determine matrix elements for ϕ_{Tg} and θ_{Tg}.
- Find higher-order terms for all target variables and consider more than two-variable dependence and increase the resolution.
- Incorporate particle Energy-losses.
- Include path length into the matrix.

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

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