Student Update

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SBS Collaboration Meeting - 2026

Mar 03 2026

New Timing Calibration procedure

Recent developments in timing calibration with 4-loop calibration script found at $SBS_REPLAY/scripts/hodo/TOFcal_consolidated.C

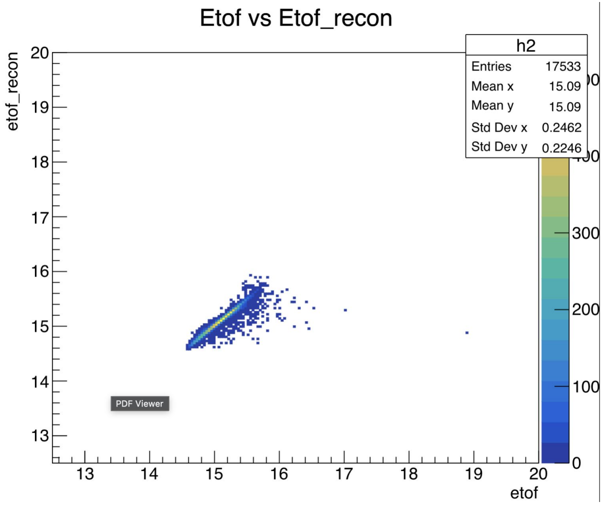
- Loop 1: Internal alignment process for the HODO
- Loop 2: RF offsets calculation
- Loop 3: HODO walk correction slope fitting, propagation delay, t0 offsets, BBCAL + HCAL + GRINCH internal alignment
- Loop 4: BBSH + BBPS + HCAL alignment with HODO

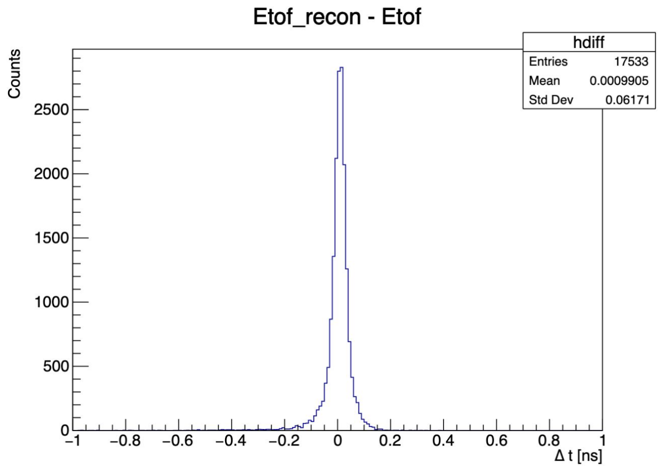
These steps have been covered in more detail in the previous talk by Jacob Koenemann.

eTOF parameters from simulations

```
# Average TOF to hodoscope based on BigBite magnet distance
bb.etof_avg =       15.1666667

bb.etof_parameters =
    -0.13668806  0 0 0 0 0
     0.48458878  1 0 0 0 0
     0.47258724  2 0 0 0 0
      3.6057646  0 1 0 0 0
      -2.809251  1 1 0 0 0
   -0.003843348  0 2 0 0 0
    -0.37526358  0 0 1 0 0
     0.22021169  1 0 1 0 0
      7.8344044  0 1 1 0 0
      2.9741023  0 0 2 0 0
     -8.9750598  0 0 0 1 0
      6.8907392  1 0 0 1 0
     -3.6159035  0 1 0 1 0
     -20.528454  0 0 1 1 0
      14.826173  0 0 0 2 0
  -1.4606378e-15  0 0 0 0 1
  -3.1371739e-15  1 0 0 0 1
   -1.024823e-16  0 1 0 0 1
  -4.2525319e-15  0 0 1 0 1
   1.4805458e-16  0 0 0 1 1
   7.7053655e-16  0 0 0 0 2
```

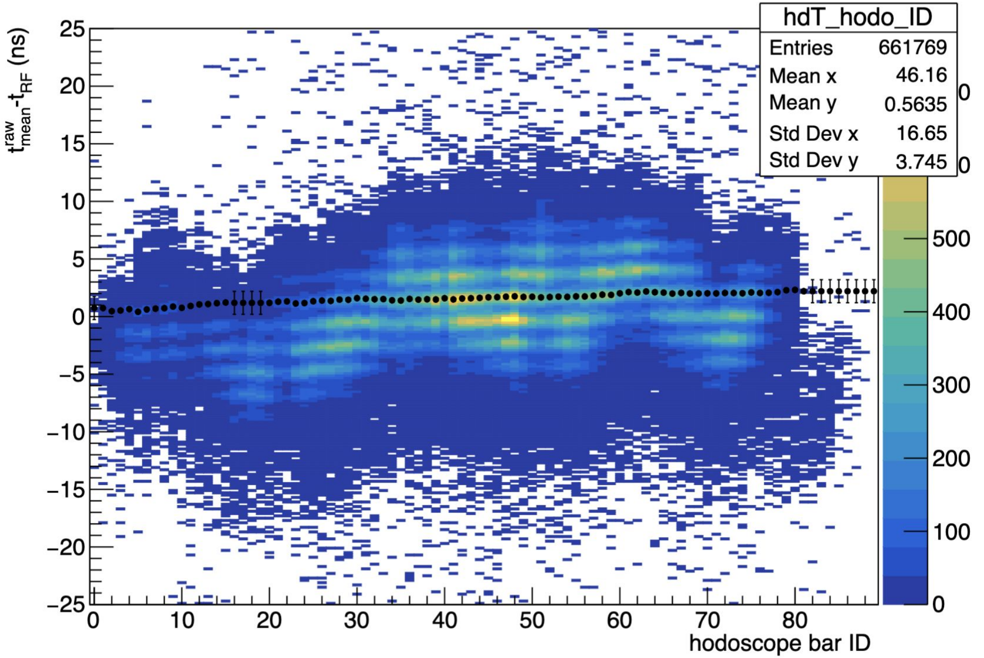




- Electron ToF variations within BB acceptance
- Replay new data with the corrected electron ToF parameters

Calibration with LH2 data

Calibration using H2 analyzer data

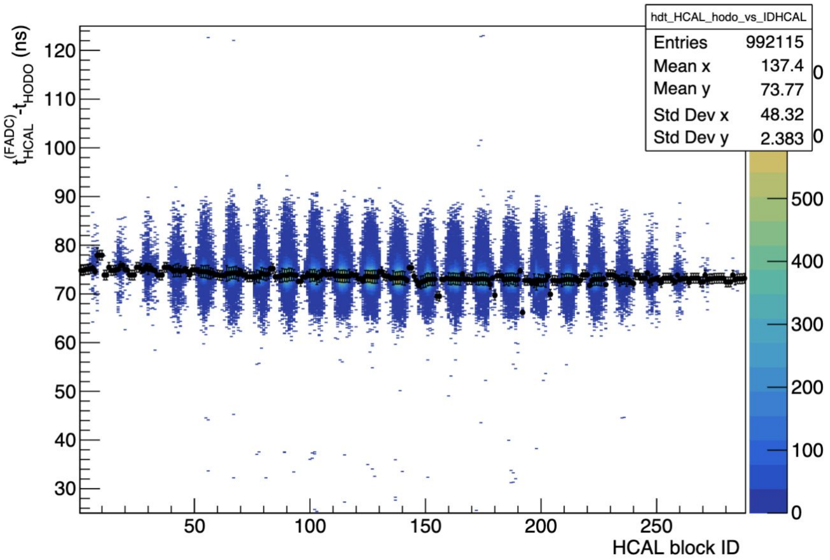


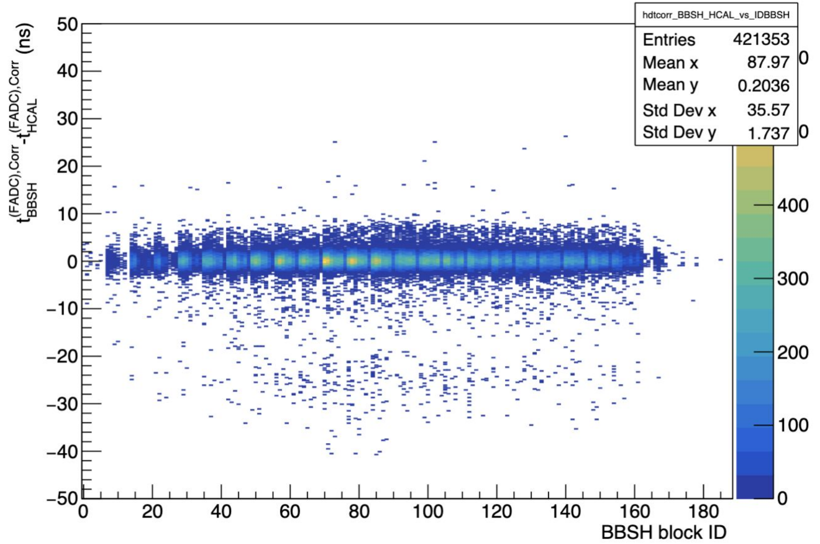
Cuts used during calibration

- sbs.hcal.nclus>0
- bb.ps.e>0.2
- abs(bb.etot_over_p[0]-1.)<0.3
- abs(bb.tr.vz[0])<0.08
- abs(sbs.hcal.atimeblk-bb.hodotdc.clus.tfinal[0]-101)<10
- sbs.hcal.e>0.02
- 0.4<W2<1.6
- dxsigma 0.08
- dysigma 0.06

- Using the sbs-replay version after the updates on Nov 11

Calibration using H2 analyzer data





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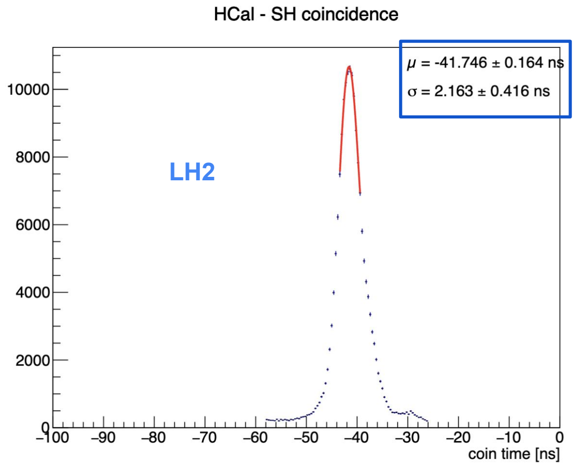
- 0.4<W2<1.6
- dxsigma 0.08
- dysigma 0.06

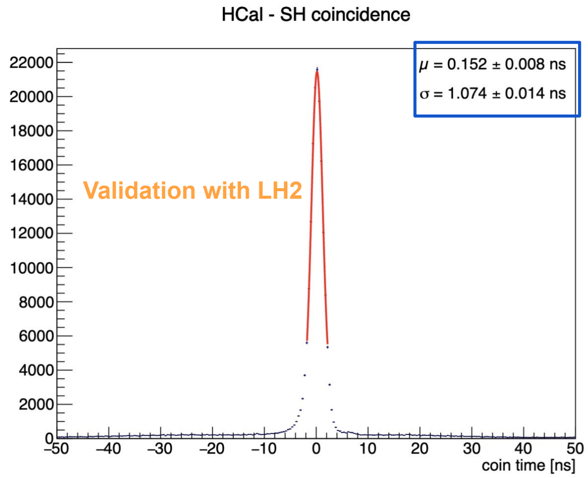
New replay results using calibrated offsets

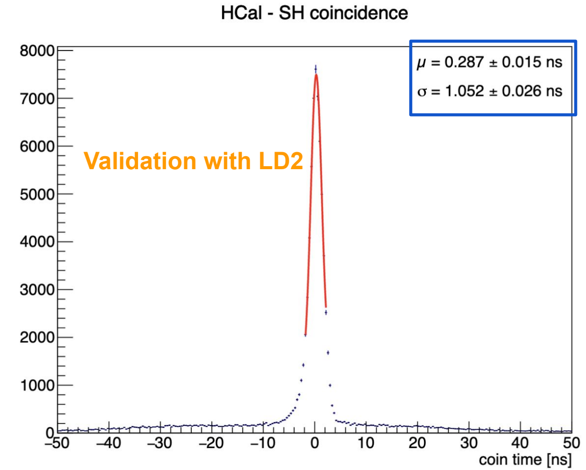


Before calibration

Cuts used for QA plots

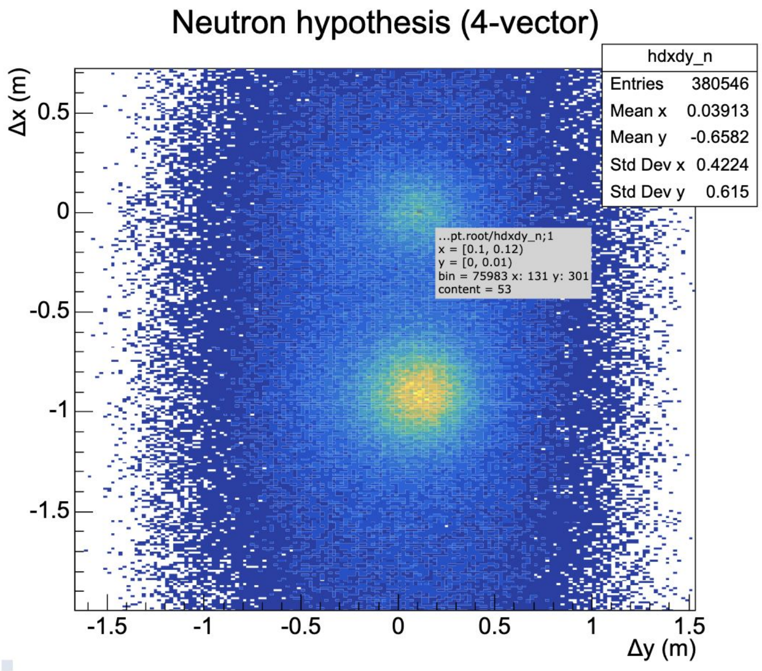
- bb.tr.n <= 0
- 0.6<W2<1.2
- abs(bb.tr.vz[0])<0.08
- bb.ps.e>0.2

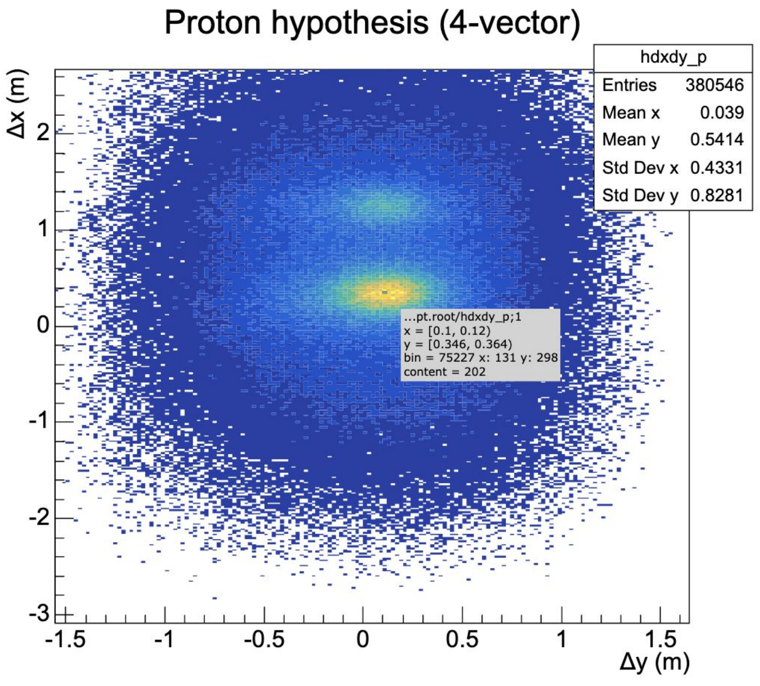




After calibration

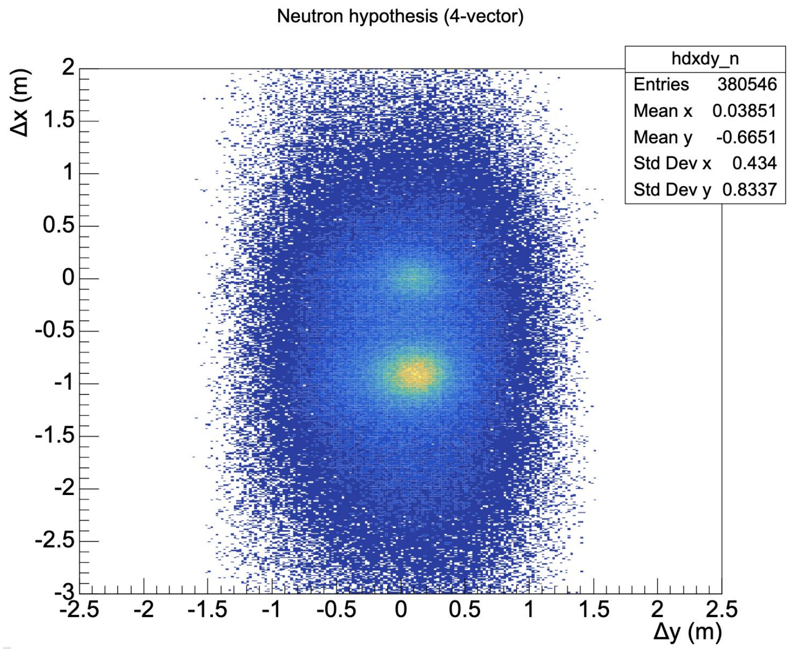
Over corrections for the proton deflection

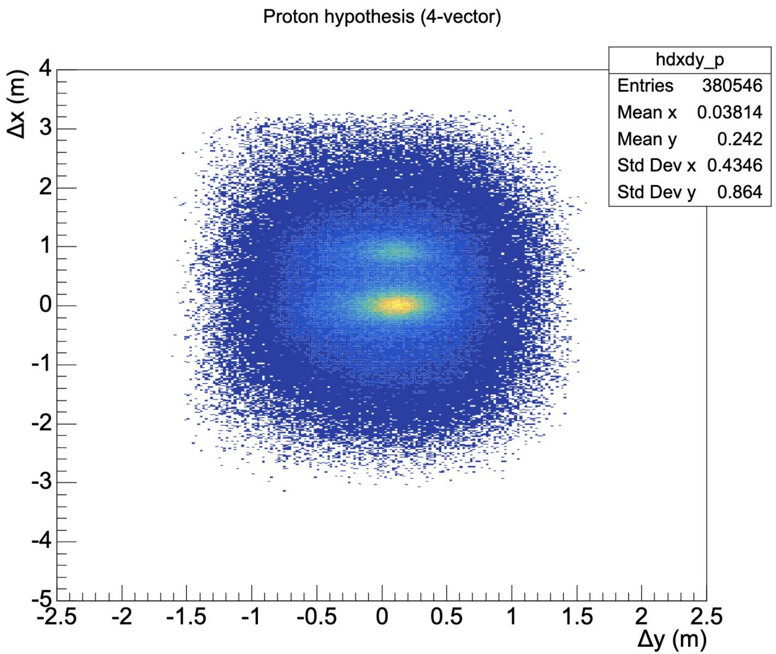




- right side plot shows the dx-dy distributions with proton bending corrections using a 1.71T SBS magnet max field(this was the value during GMn)
- clear overcorrection for the magnet bending, max field is too high
- back of the envelope calculation done for sbs max field assuming a uniform SBS magnetic field

After back of the envelope calculations for SBS max field

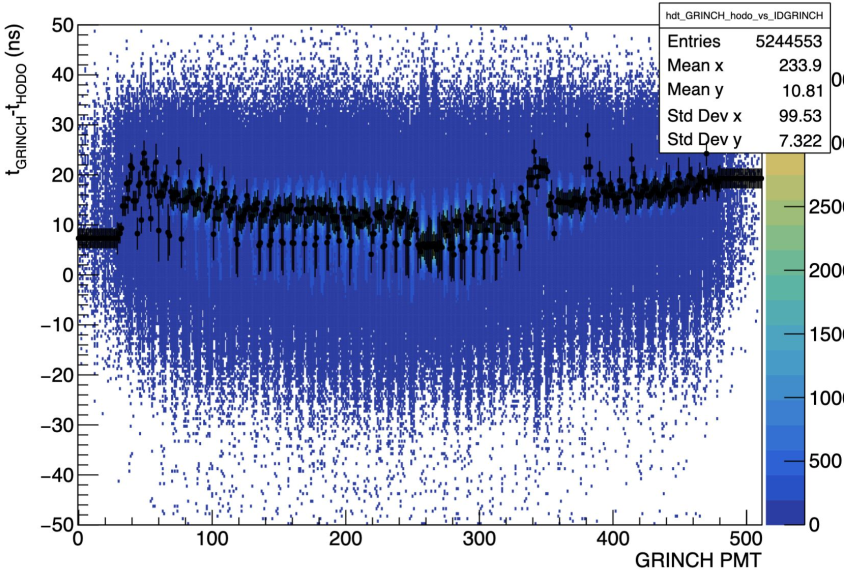


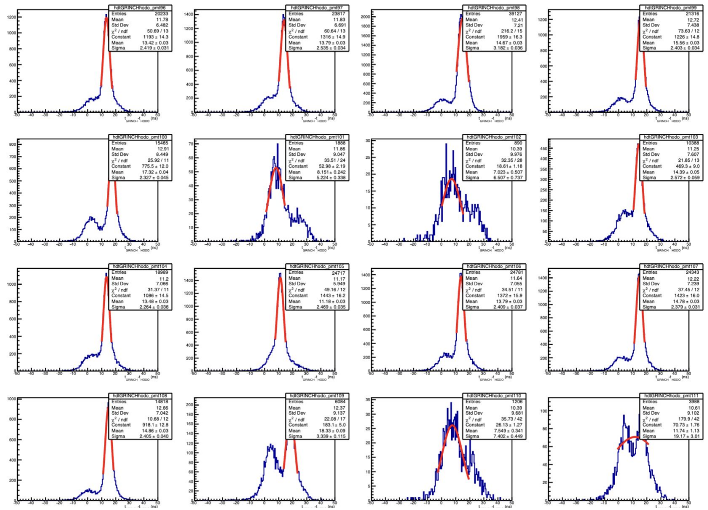


- better proton bending approximations with new SBS max field value
- corrected SBS max field value = 1.266T

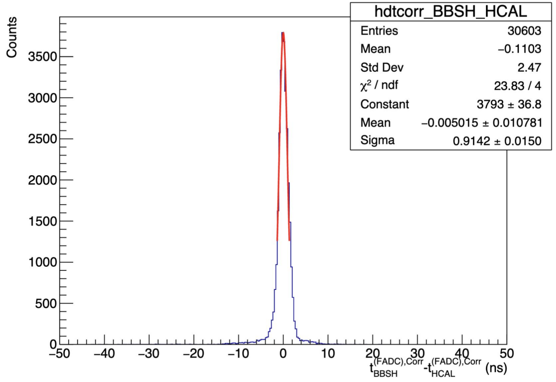
Calibration with newest version of calibration scripts
LD2 data

Results and misbehaviour in GRINCH





- Work is in progress for improving this
- Possible fixes include using lower current data for calibrations and using closely chosen cuts



Spin Precession and Polarization Transfer

Asymmetry and Likelihood Function

Given polarization of the recoiling nucleon at the target $P = (P_x, P_y, P_z)$

$$N^{\pm}(P,S) = N_0^{\pm}\frac{\epsilon}{2\pi}\Big[1 + \big(a_1 \pm hA_y \sum_{j=x,z} S_{yj}P_j + A_y S_{yy} P_y\big)\cos\phi \\ + \big(b_1 \mp hA_y \sum_{j=x,z} S_{xj}P_j - A_y S_{xy} P_y\big)\sin\phi \\ + a_2\cos 2\phi + b_2 \sin 2\phi + \cdots\Big].$$

The likelihood function of the target polarizations is generated by taking the product of +- asymmetry over all events

$$L(P) = \prod_{i=1}^{N_{\text{event}}} \frac{1}{2\pi}\Bigg[1 + \big(a_1 + h\,\epsilon_i A_y^{(i)} \sum_{j=x,z} S_{yj}^{(i)} P_j + A_y^{(i)} S_{yy}^{(i)} P_y\big)\cos\phi_i \\ + \big(b_1 - h\,\epsilon_i A_y^{(i)} \sum_{j=x,z} S_{xj}^{(i)} P_j - A_y^{(i)} S_{xy}^{(i)} P_y\big)\sin\phi_i \\ + a_2\cos 2\phi_i + b_2\sin 2\phi_i + \cdots\Bigg].$$

Reference: Andrew Puckett thesis

Extraction of Polarizations at the Target

Maximizing the logarithm of the likelihood function gives

$$\sum_{i=1}^{N_{\text{event}}} \begin{pmatrix} \lambda_x^{(i)}(1-\lambda_0^{(i)}) \\ \lambda_y^{(i)}(1-\lambda_0^{(i)}) \\ \lambda_z^{(i)}(1-\lambda_0^{(i)}) \end{pmatrix} = \sum_{i=1}^{N_{\text{event}}} \begin{pmatrix} (\lambda_x^{(i)})^2 & \lambda_x^{(i)}\lambda_y^{(i)} & \lambda_x^{(i)}\lambda_z^{(i)} \\ \lambda_y^{(i)}\lambda_x^{(i)} & (\lambda_y^{(i)})^2 & \lambda_y^{(i)}\lambda_z^{(i)} \\ \lambda_z^{(i)}\lambda_x^{(i)} & \lambda_z^{(i)}\lambda_y^{(i)} & (\lambda_z^{(i)})^2 \end{pmatrix} \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$$

where,

$$\lambda_0^{(i)} \equiv a_1 \cos\phi_i + b_1 \sin\phi_i + a_2 \cos 2\phi_i + b_2 \sin 2\phi_i + \cdots$$

$$\lambda_x^{(i)} \equiv h\,\epsilon_i A_y^{(i)} S_{yx}^{(i)} \cos\phi_i - S_{xx}^{(i)} \sin\phi_i$$

$$\lambda_y^{(i)} \equiv A_y^{(i)} S_{yy}^{(i)} \cos\phi_i - S_{xy}^{(i)} \sin\phi_i$$

$$\lambda_z^{(i)} \equiv h\,\epsilon_i A_y^{(i)} S_{yz}^{(i)} \cos\phi_i - S_{xz}^{(i)} \sin\phi_i$$

Now we need to obtain the Spin Transport Matrix, Analyzing Power and False Asymmetry terms

Reference: Andrew Puckett thesis

Spin Transport Matrix

$$S = R_2 M R_1$$

- M_{ij}: the matrix element coupling the i^th component of the spin at the focal plane to the j^th component of the spin at the target
- R_1: reaction plane coordinates to transport coordinates
- R_2: transport coordinates to comoving coordinates(of the particle at the polarimeter)

$$M_{ij}(x_{tar}, y_{tar}, x'_{tar}, y'_{tar}, \delta) = \sum_{\alpha,\beta,\lambda,\mu,\nu=0}^{\alpha+\beta+\lambda+\mu+\nu\leq 5} C_{ij}^{\alpha\beta\lambda\mu\nu}\, x_{tar}^{\alpha}\, y_{tar}^{\beta}\, {x'_{tar}}^{\lambda}\, {y'_{tar}}^{\mu}\, \delta^{\nu}$$

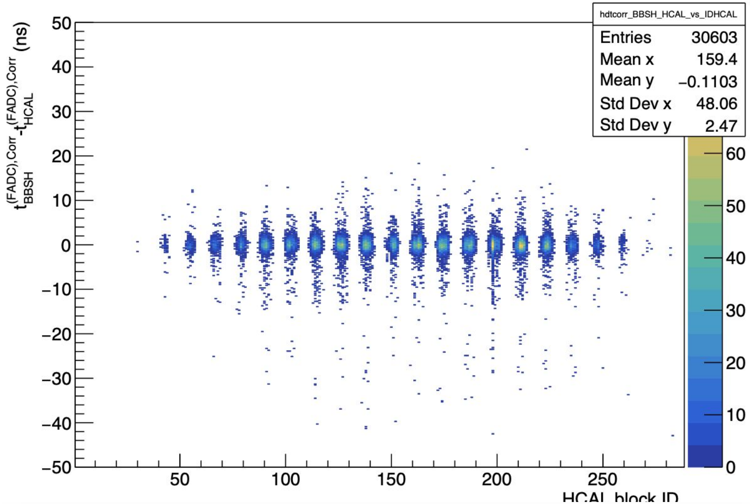
- the generation of the coefficients used for this matrix element requires accurate inputs from simulation of the spin precession through SBS magnet
- unfortunately, GEANT-4(therefore G4SBS) itself does not include an accurate methodology to calculate spin precession for the neutron as it does for the proton
- David Hamilton is developing local branch in GEANT-4 that facilitates this and that will be used for this exercise

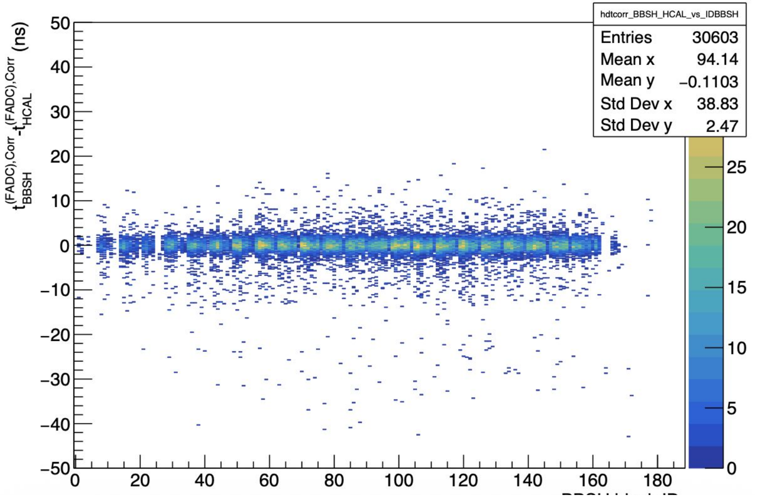
Reference: Andrew Puckett thesis

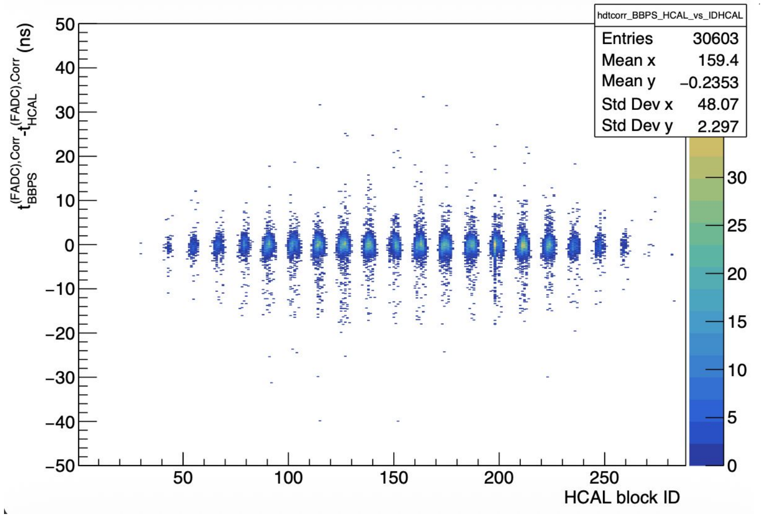
Thank You!

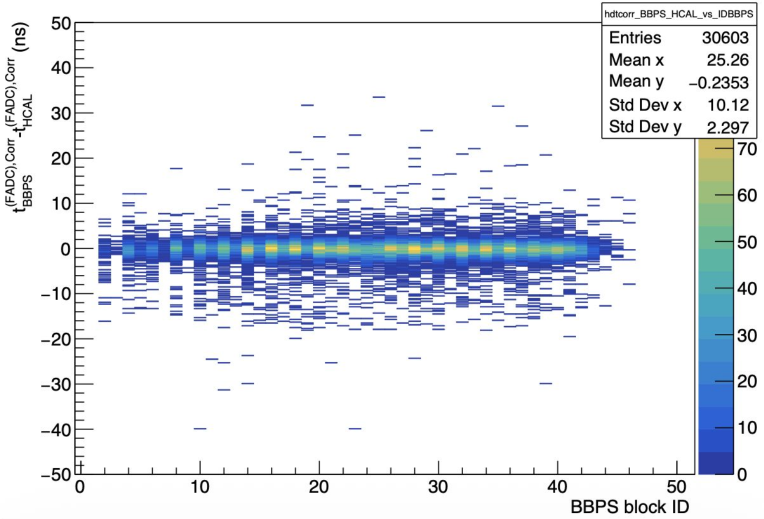
Backups

Backups

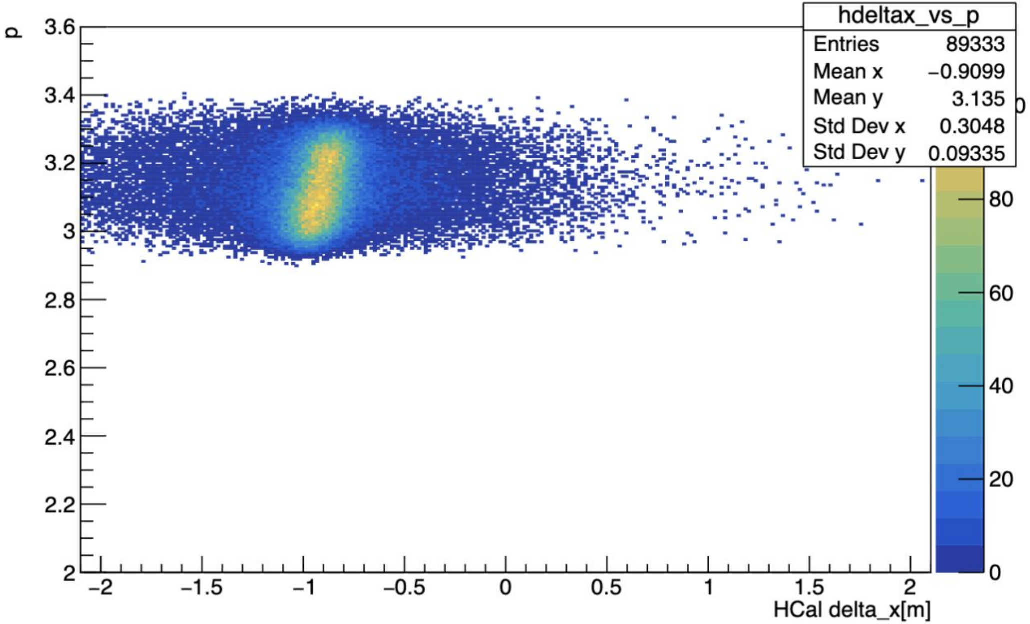

hdtcorr_BBSH_HCAL_vs_IDHCAL
Entries 30603
Mean x 159.4
Mean y −0.1103
Std Dev x 48.06
Std Dev y 2.47
$t_{BBSH}^{(FADC),Corr}-t_{HCAL}^{(FADC),Corr}$ (ns)

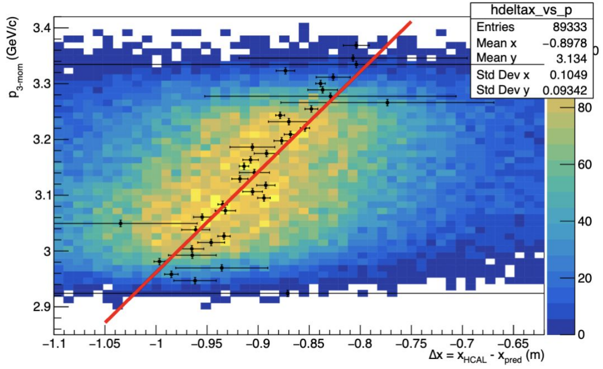

hdtcorr_BBSH_HCAL_vs_IDBBSH
Entries 30603
Mean x 94.14
Mean y −0.1103
Std Dev x 38.83
Std Dev y 2.47
$t_{BBSH}^{(FADC),Corr}-t_{HCAL}^{(FADC),Corr}$ (ns)


hdtcorr_BBPS_HCAL_vs_IDHCAL
Entries 30603
Mean x 159.4
Mean y −0.2353
Std Dev x 48.07
Std Dev y 2.297
$t_{BBPS}^{(FADC),Corr}-t_{HCAL}^{(FADC),Corr}$ (ns)
HCAL block ID


hdtcorr_BBPS_HCAL_vs_IDBBPS
Entries 30603
Mean x 25.26
Mean y −0.2353
Std Dev x 10.12
Std Dev y 2.297
$t_{BBPS}^{(FADC),Corr}-t_{HCAL}^{(FADC),Corr}$ (ns)
BBPS block ID

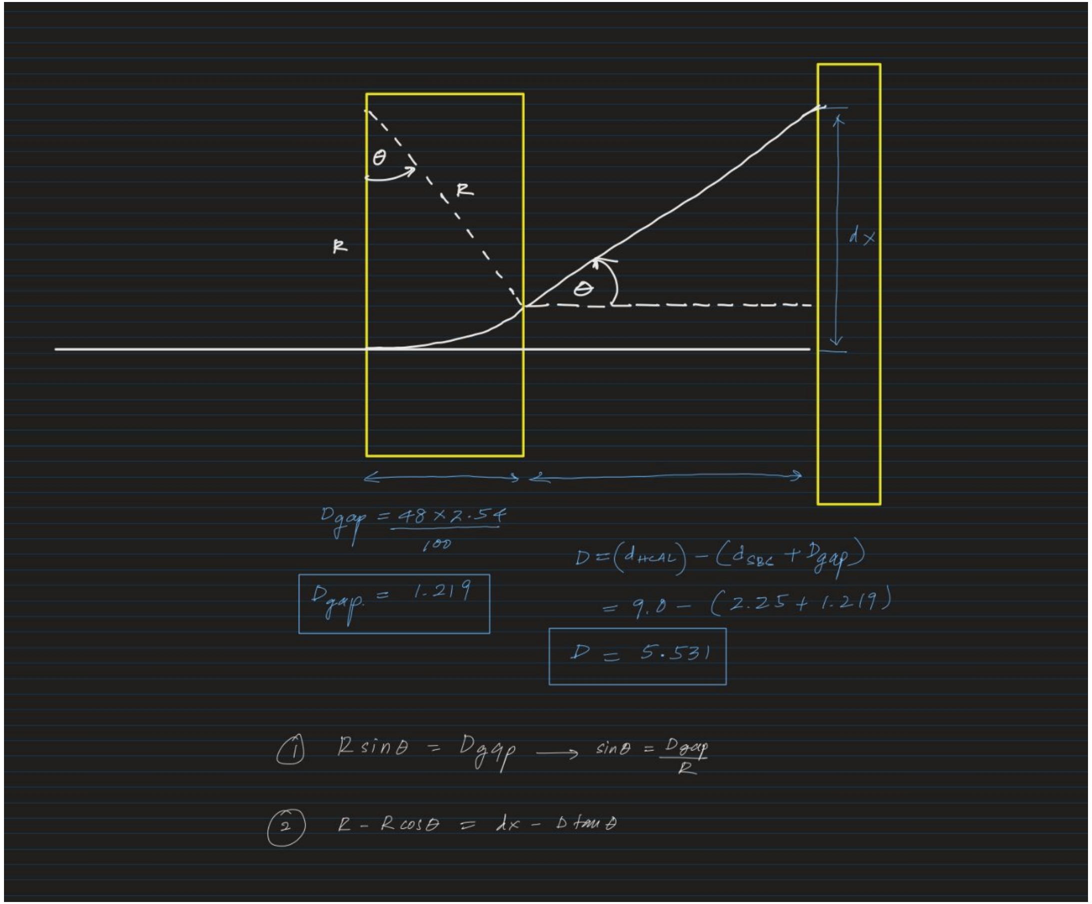
Finding dx at the central proton momentum



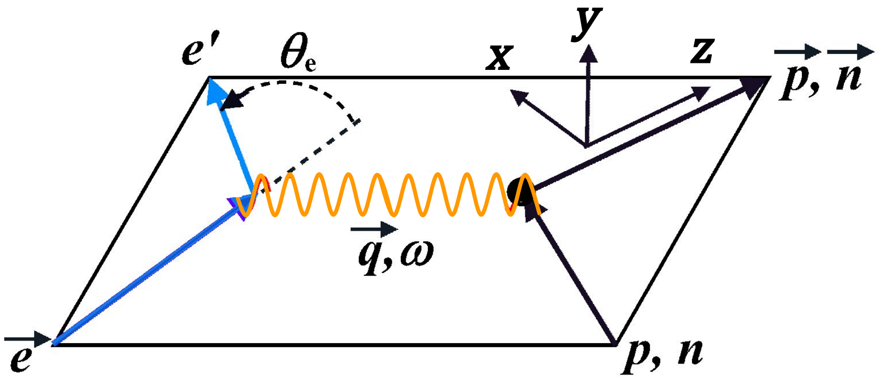


P_central ~ 3.13 GeV/c
dx ~ -0.915 m

```
sbsfield_temp = pp_etheta/0.299792458/Radius
```



- The unpolarized target is struck with the polarized electron beam
- The transferred polarization to the recoiling neutron can be parameterized using the Sachs FFs as follows
- The x component below denotes the transverse polarization and the z component denotes the longitudinal polarization of the recoiling neutron



$$
\begin{aligned}
P_x &= -hP_e \frac{2\sqrt{\tau(1+\tau)}\tan\frac{\theta_e}{2} G_E G_M}{G_E^2 + \tau G_M^2 (1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}} \\
P_y &= 0 \\
P_z &= hP_e \frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2\frac{\theta_e}{2}}\tan\frac{\theta_e}{2} G_M^2}{G_E^2 + \tau G_M^2 (1 + 2(1+\tau)\tan^2\frac{\theta_e}{2})}
\end{aligned}
$$

- The ratio of the transferred polarization will be a direct measurement of the neutron FF ratio (while cancelling many of the systematic errors)

$$
\frac{P_x}{P_z} = \frac{1}{\sqrt{\tau + \tau(1+\tau)\tan^2\frac{\theta_e}{2}}} \cdot \frac{G_E}{G_M}
$$

$$
\begin{aligned}
P_x^* &= A_y^{eff} P_e P_x \\
P_y^* &= A_y^{eff} P_e P_z \sin\chi
\end{aligned}
$$

Asymmetry and Likelihood Function

Given polarization of the recoiling nucleon at the target ***P = (P_x, P_y, P_z)***

$$N^{\pm}(P,S) = N_0^{\pm}\,\frac{\epsilon}{2\pi}\Big[1 + \Big(a_1 \pm hA_y \sum_{j=x,z} S_{yj}P_j + A_y S_{yy} P_y\Big)\cos\phi$$
$$+ \Big(b_1 \mp hA_y \sum_{j=x,z} S_{xj}P_j - A_y S_{xy} P_y\Big)\sin\phi$$
$$+ a_2 \cos 2\phi + b_2 \sin 2\phi + \cdots\Big].$$

$N^{\pm}(P,S)$: Yield for $\pm$ beam helicity

h: Beam polarization

A_y: Analyzing power

P_j: Polarization components ($j = x, z$)

Reference: Andrew Puckett thesis

Asymmetry and Likelihood Function

The likelihood function of the target polarizations is generated by taking the product of +- asymmetry over all events

$$L(P) = \prod_{i=1}^{N_{\text{event}}} \frac{1}{2\pi} \Big[1 + \big(a_1 + h\,\epsilon_i A_y^{(i)} \sum_{j=x,z} S_{yj}^{(i)} P_j + A_y^{(i)} S_{yy}^{(i)} P_y \big) \cos\phi_i$$

$$+ \big(b_1 - h\,\epsilon_i A_y^{(i)} \sum_{j=x,z} S_{xj}^{(i)} P_j - A_y^{(i)} S_{xy}^{(i)} P_y \big) \sin\phi_i$$

$$+ a_2 \cos 2\phi_i + b_2 \sin 2\phi_i + \cdots \Big].$$

ϵ_i

A_y: Analyzing power

S: Spin rotation (3x3 matrix)

ϕ_i: Azimuthal scattering angle

Reference: Andrew Puckett thesis

R_1 Rotation

$$\begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}_{\text{transport}} = \begin{pmatrix} \hat{t}_x & \hat{n}_x & \hat{l}_x \\ \hat{t}_y & \hat{n}_y & \hat{l}_y \\ \hat{t}_z & \hat{n}_z & \hat{l}_z \end{pmatrix} \begin{pmatrix} P_t \\ P_n \\ P_l \end{pmatrix}.$$

where

$$\mathbf{k} = \left(0,\ \sin\Theta_{\mathrm{SBS}},\ \cos\Theta_{\mathrm{SBS}}\right),$$

$$\hat{\mathbf{q}} = \frac{1}{\sqrt{1 + x'^2_{\text{tar}} + y'^2_{\text{tar}}}}\left(x'_{\text{tar}},\ y'_{\text{tar}},\ 1\right).$$

$$\hat{\ell} \equiv \hat{q}, a$$

$$\hat{n} \equiv \frac{\hat{q} \times \hat{k}}{|\hat{q} \times \hat{k}|},$$

$$\hat{t} \equiv \hat{n} \times \hat{\ell}.$$

Reference: Andrew Puckett thesis

R_2 Rotation

$$\begin{pmatrix} P_x^{\text{fpp}} \\ P_y^{\text{fpp}} \\ P_z^{\text{fpp}} \end{pmatrix} = \begin{pmatrix} \hat{x}_x & \hat{y}_x & \hat{z}_x \\ \hat{x}_y & \hat{y}_y & \hat{z}_y \\ \hat{x}_z & \hat{y}_z & \hat{z}_z \end{pmatrix} \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}_{\text{transport}} .$$

where

$$\hat{z} = \frac{1}{\sqrt{1 + {x'_{\mathrm{fp}}}^2 + {y'_{\mathrm{fp}}}^2}} \begin{pmatrix} x'_{\mathrm{fp}} \\ y'_{\mathrm{fp}} \\ 1 \end{pmatrix}$$

$$\hat{y} = \frac{\hat{z} \times \hat{x}_{\mathrm{transport}}}{\left|\hat{z} \times \hat{x}_{\mathrm{transport}}\right|}$$

$$\hat{x} = \hat{y} \times \hat{z}$$

Reference: Andrew Puckett thesis