Solved & Unsolved Mysteries in Run I CTC Tracking

(Title provided by Dave Gerdes)

Bill Ashmanskas

University of Chicago

Typical Clues

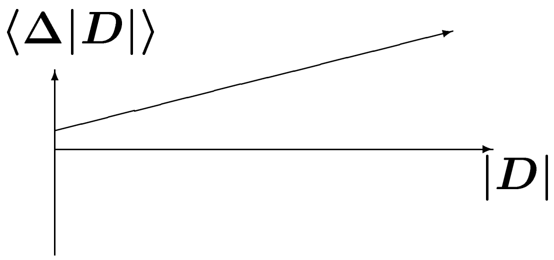
How do you check how well the tracking is doing?

Internal consistency: How well do the hits on the track agree with the trajectory (e.g. helix)?

(notation: $\phi_0 = 0$; track is y, z vs. x or r)
$\Delta|D| = |D_{\mathrm{hit}}| - |D_{\mathrm{track}}| =$ distance residual
$\Delta y = y_{\mathrm{hit}} - y_{\mathrm{track}} =$ position residual

rms(Δy) vs layer $\rightarrow$ hit resolution (is it much worse than expected?)

$\langle \Delta|D| \rangle \rightarrow t_0$ or other calibration constant



As a dumb example, a plot like this would indicate a drift velocity problem and a small t_0 problem.

Drift model problems tend to bias $|D|$ but average out over drift signs. Displacing a wire will bias y and thus directly the fitted helix.

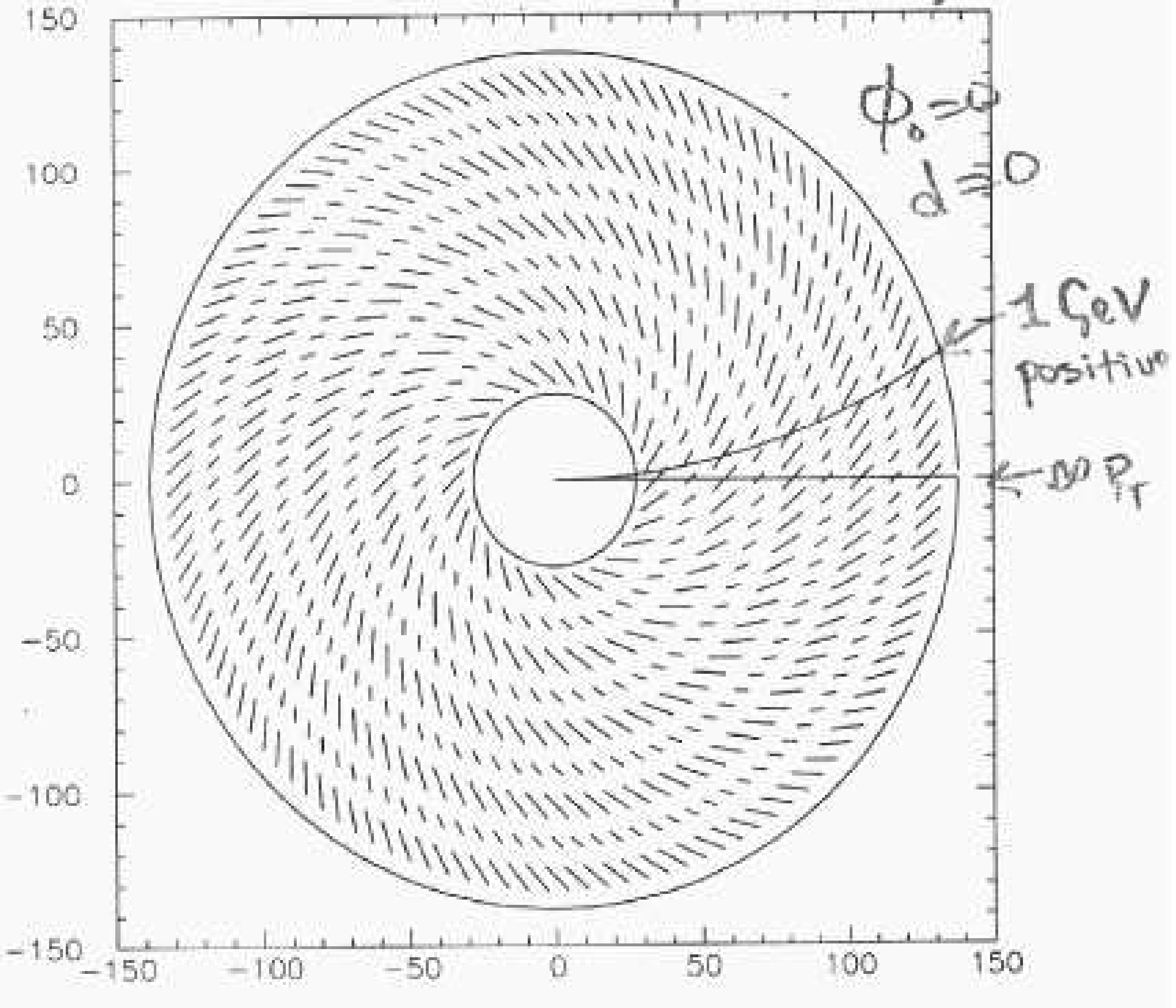
"Calibration" seeks to minimize rms(Δy) by doing a regression of $\Delta|D|$ vs drift model parameters. The hard part is picking the right parameters.

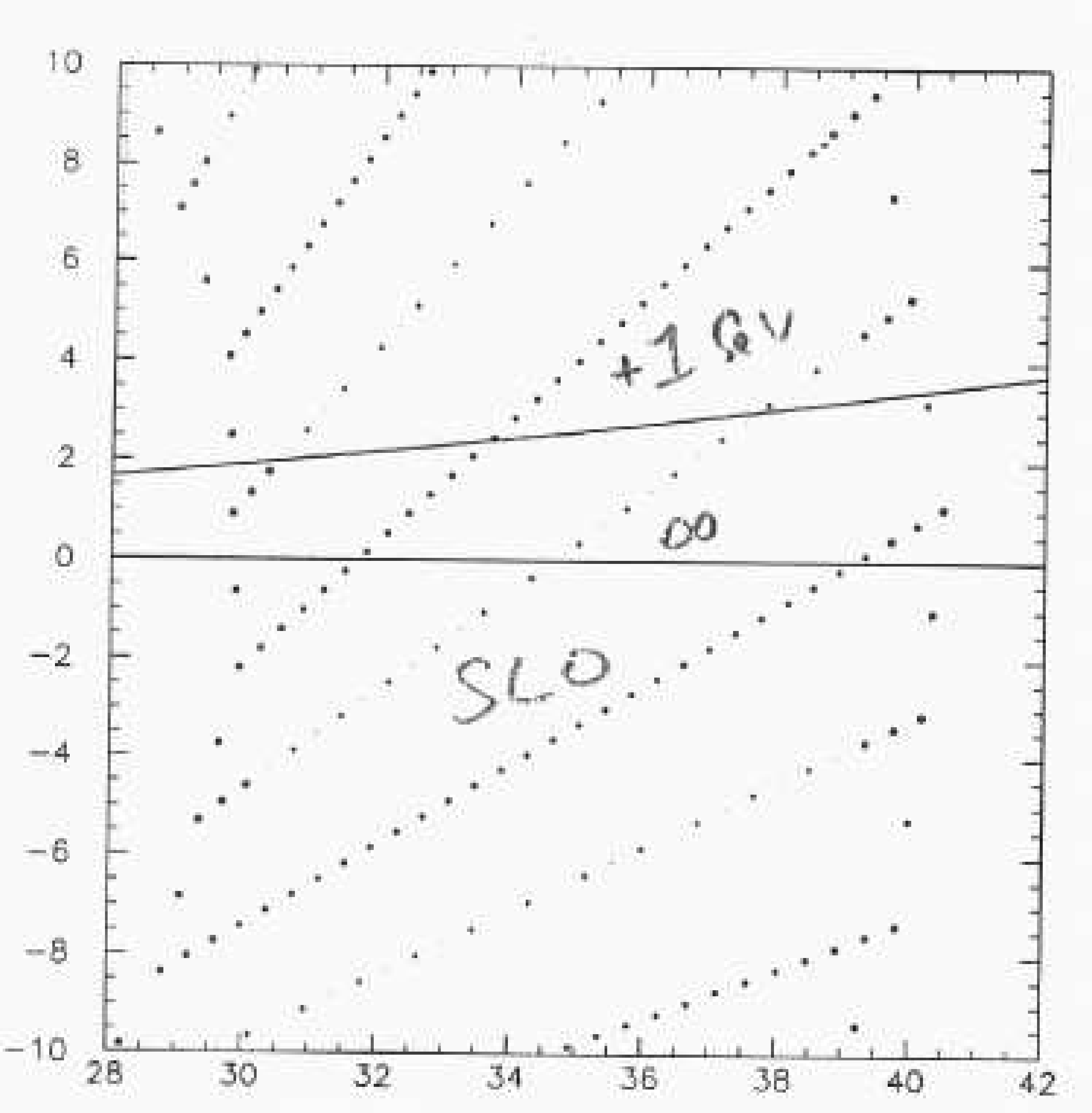
(There will be a small calibration mystery later.)

$y = ar^2 + b$

where $a = \frac{c}{1+2cd}$, $b = \frac{d(1+cd)}{1+2cd}$

and $\phi_0 = 0$ w.l.o.g.



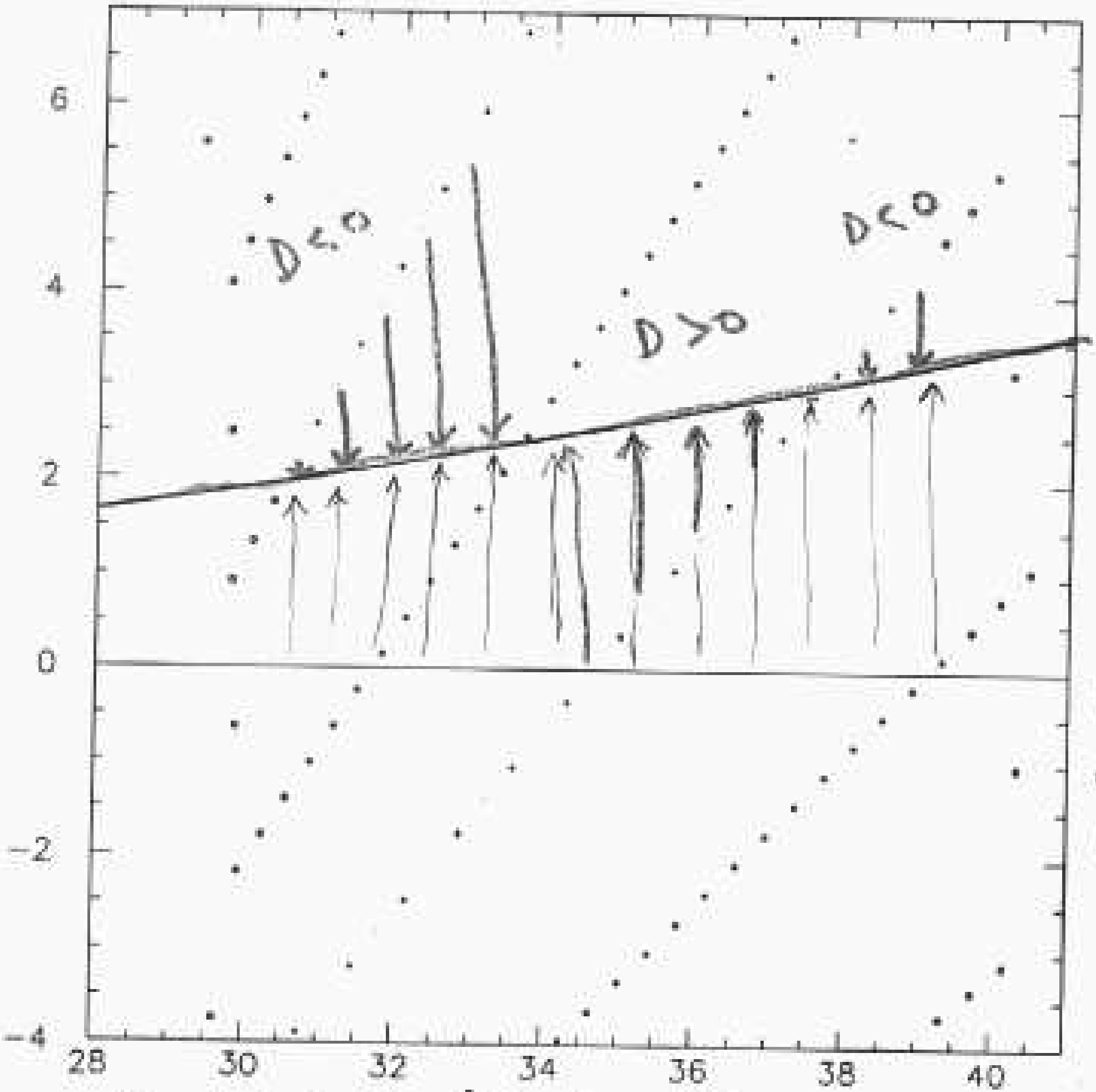


10
8
6
4
2
0
−2
−4
−6
−8
−10
28
30
32
34
36
38
40
42
+1 GV
∞
SLO

$y = ar^2 + b$

where $a = \frac{-c}{1+2cd}$, $b = \frac{d(1+cd)}{1+2cd}$

and $\phi_0 = 0$ w.l.o.g.



(I didn't draw any hits)

"late" hit: $|D_{hit}| > |D_{track}|$

"early" hit: $|D_{hit}| < |D_{track}|$

$|D_{hit}| - |D_{track}| = (y_{hit} - y_{track}) \cdot \text{sign}(D_{track})$

where for simplicity I'm ignoring any angle between $\hat{y}$ and $\hat{D}$

Clues, Continued

External consistency: How well do track parameters agree with constraints from other detectors, other tracks, etc.

- CTC vs beamline: $\langle d_{\mathbf{beam}} \rangle$ vs ϕ
  ("false impact parameter")
- CTC vs SVX and VTX
  (when they disagree, you have to decide which one to move)
- CTC vs CEM: $\langle E/p \rangle$ e^+ vs e^-
  ("false curvature")
- decays (ψ, Υ, Z, K_s, Λ, ($\gamma \rightarrow ee$))
  (common vertex, known mass; measure resolutions, biases)
  ($\psi \rightarrow \mu\mu$ has been most fruitful)

Mystery #1: Unsolved

Infamous "factor of 2" on track parameter resolutions.

From track fit, measure rms Δy by SL (Ib W electrons) to be

SL	0	1	2	3	4	5	6	7	8
rms (μm)	265	210	205	210	172	220	170	158	157

Using derivaties $d\vec{y}_{\rm hit}/d\vec{\alpha}$ and pattern of used hits, construct a covariance matrix V on $\vec{\alpha}$; "predict" parameter resolutions $\sqrt{V_{ii}}$.

Using external information, find "observed" parameter resolutions, e.g. for Ib $W \to e\nu$ and $Z \to ee$ samples (using production constants).

parameter	predict	observe	ratio
d_0	285 μm	570 μm	2.0
z_0	0.45 cm	1.0 cm	2.2
$1/p_T$ (no BC)	0.17 %/GeV	0.30 %/GeV	1.8
$1/p_T$ (BC)	0.06 %/GeV	0.10 %/GeV	1.7

This is well known. Similar numbers illustrated in various Run Ia track samples in CDF 1939 by Bedeschi et al.

Mystery #2: Solved

1.7 milliradian rotation of $\vec{B}$ away from CTC $\vec{z}$-axis, mostly in x-z plane

$M(\psi)$ vs $\phi(\psi)$ had amplitude $\propto \eta(\psi)$, $\sim$ 5 MeV at $\eta \approx 0.8$.

Corrected with $P_T \rightarrow P_T \times (1 - .0017 \cot\theta \sin(\phi_0 - 1.9))$ (CDF 3972, YK Kim).

Explanation/derivation written up nicely by JPB.

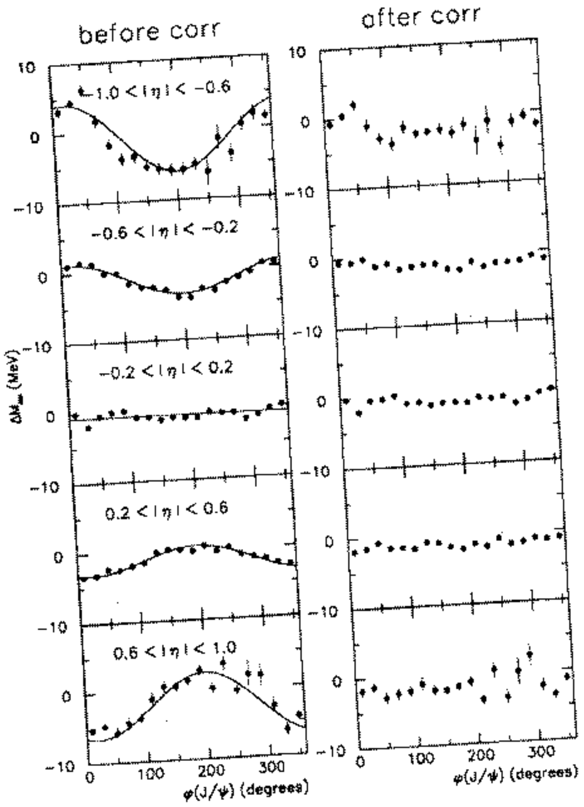


Figure 7: Measured J/ψ mass as a function of $\phi_{J/\psi}$ in various $\eta_{J/\psi}$ regions, before (left) and after (right) the B-field axis correction.

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Mystery #3: Mostly Solved

W mass track recipe (as of early 1997):

$$\begin{aligned} \mathbf{1\ GeV}/qp_T \rightarrow \mathbf{1\ GeV}/qp_T \\ -0.000056 \\ -0.00028\ (\cot\theta + z_0/81\ \mathrm{cm}) \\ -0.000040\ \sin(\phi_0 - 3.0) \end{aligned}$$

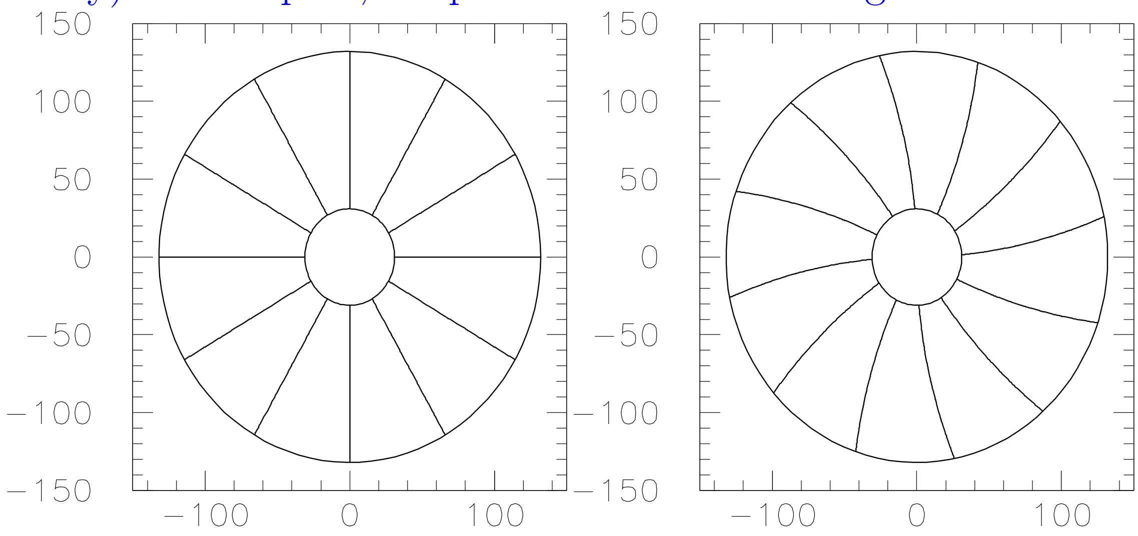
$$\cot\theta \rightarrow 0.9986\ \cot\theta$$

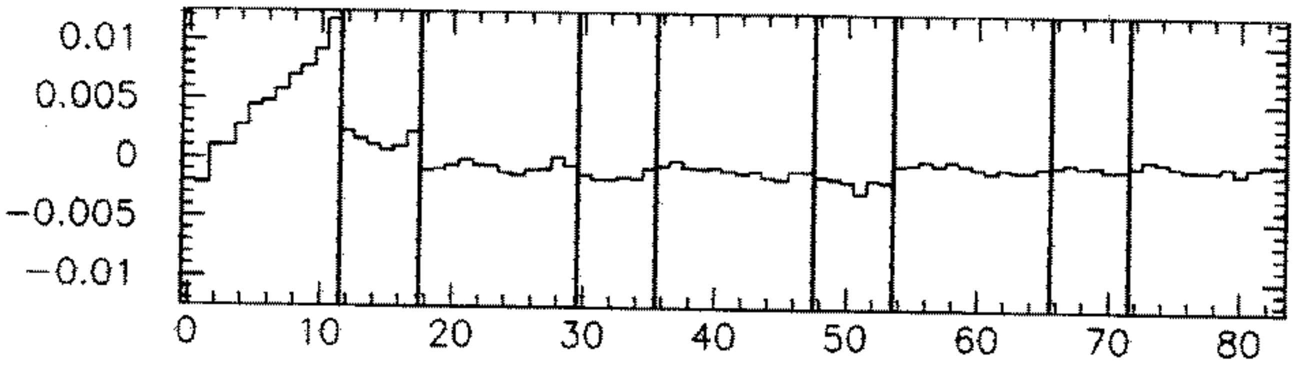
- #1 and #2 should have been taken out by Run Ia WPO alignment
- #3 should vanish if CTC and SVX agree on beamline (corresponds approximately to 60 μm offset along $\hat{x}$)
- #4 was always a mystery

Mystery #3, continued

Alignment procedure (CDF 1002, CDF 4456)

- Use $\boldsymbol{W}$ electron sample (40K events Run Ib after cuts)
- Constrain $\boldsymbol{z_0}$ (VTVZ), $\boldsymbol{d_0}$ (beamline), and $\boldsymbol{c}$ (CEM). CTC then provides only $\boldsymbol{\phi_0}$ and $\mathbf{cot}\,\boldsymbol{\theta}$.
- Float φ offsets, layer by layer, for E and W endplates separately.
- Fix $\boldsymbol{(E + W)/2}$ at some axial SL (Ia=SL4, Ib=SL8); also fix $\boldsymbol{(E + W)/2}$ at SL7 (Ib only).
- Fix $\boldsymbol{E - W}$ at SL8 (Ib only). Survey most accurately ruled out relative endplate rotation at outer radius.
- Fix $\boldsymbol{E - W}$ at SL1,7 to agree with calculated endplate deflection (Ib only). In the past, endplate deflection was neglected.





Mystery #3, continued

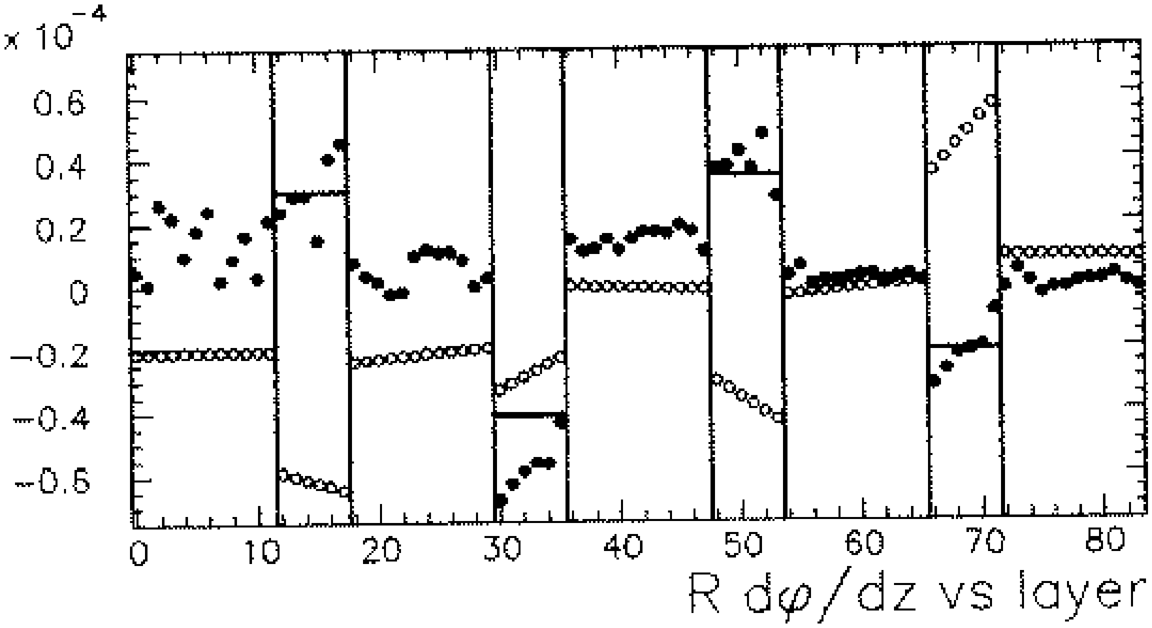


Figure 9: For Ib alignment (solid points) and Ia alignment (open circles), we show $r_i \frac{d\varphi_i}{dz} (= r_i B_i)$ for each layer i. The horizontal line segments show the values implied by the calculated endplate deflection in the stereo layers. The Ib alignment constrained SL1 and SL7 to agree with the calculation, and constrained SL8 to zero.

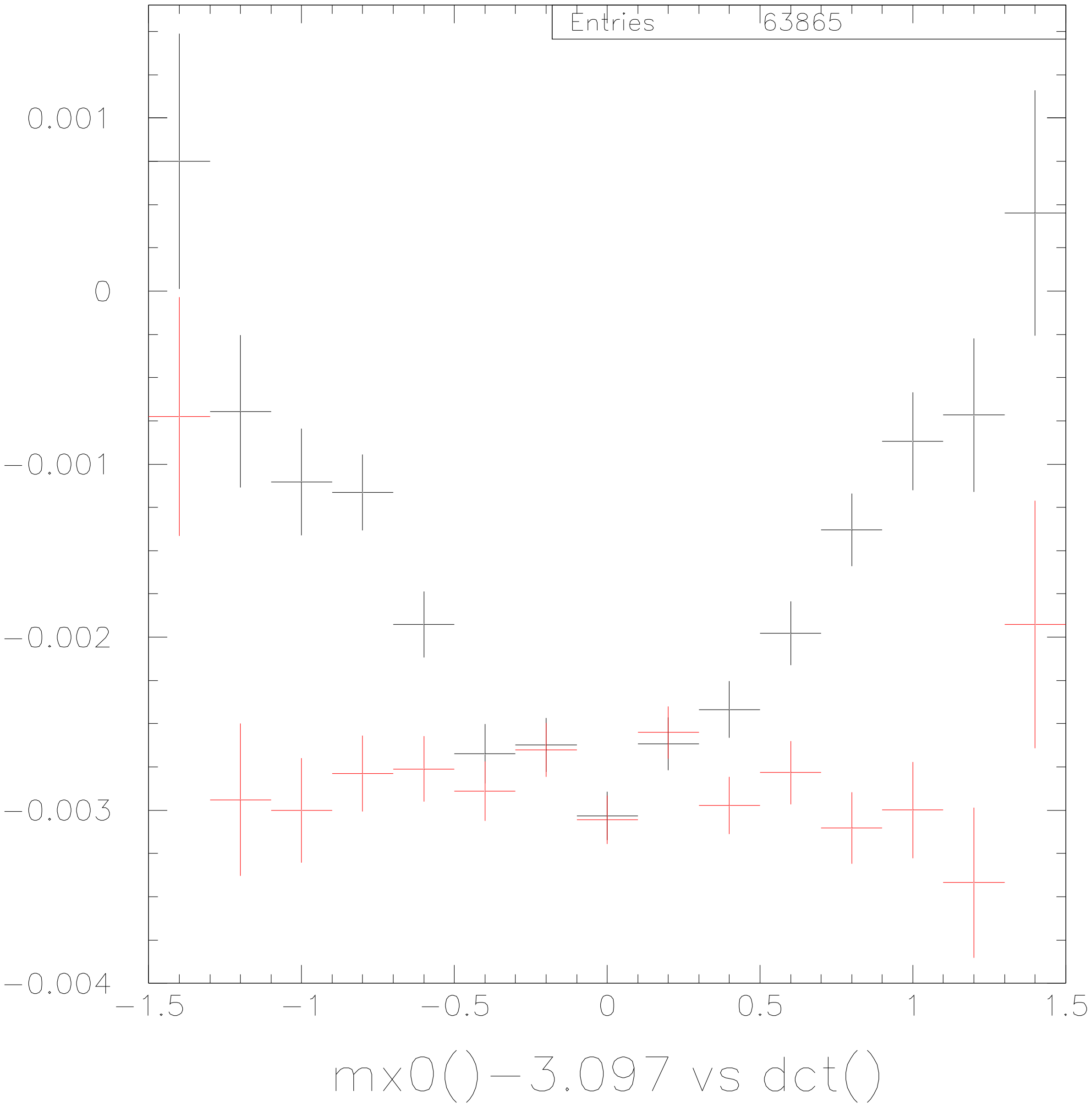
From CDF 4456

False $\frac{1}{2R}$	LJN	us, old WPO	us, new WPO
overall	$.000056 \pm .000008$	$.000044 \pm .000009$	$.000002 \pm .000006$
λ	$.00028 \pm .00002$	$.00024 \pm .00001$	$-.00001 \pm .00001$
$z_0/187/.00028$	2.3 ± 0.3	2.6 ± 0.2	0.2 ± 0.2
$\sin(\phi_0 - 3.0)$	$.00040 \pm .00002$	$.00033 \pm .00001$	$.00032 \pm .00001$

Table 2: False curvatures (LJN cm = GeV = 1 unit convention) in Ib W electrons, using Ia WPO and using Ib WPO. We also list the values extracted by LJN, to show that there is a strong correlation between what we're measuring and what he's measuring.

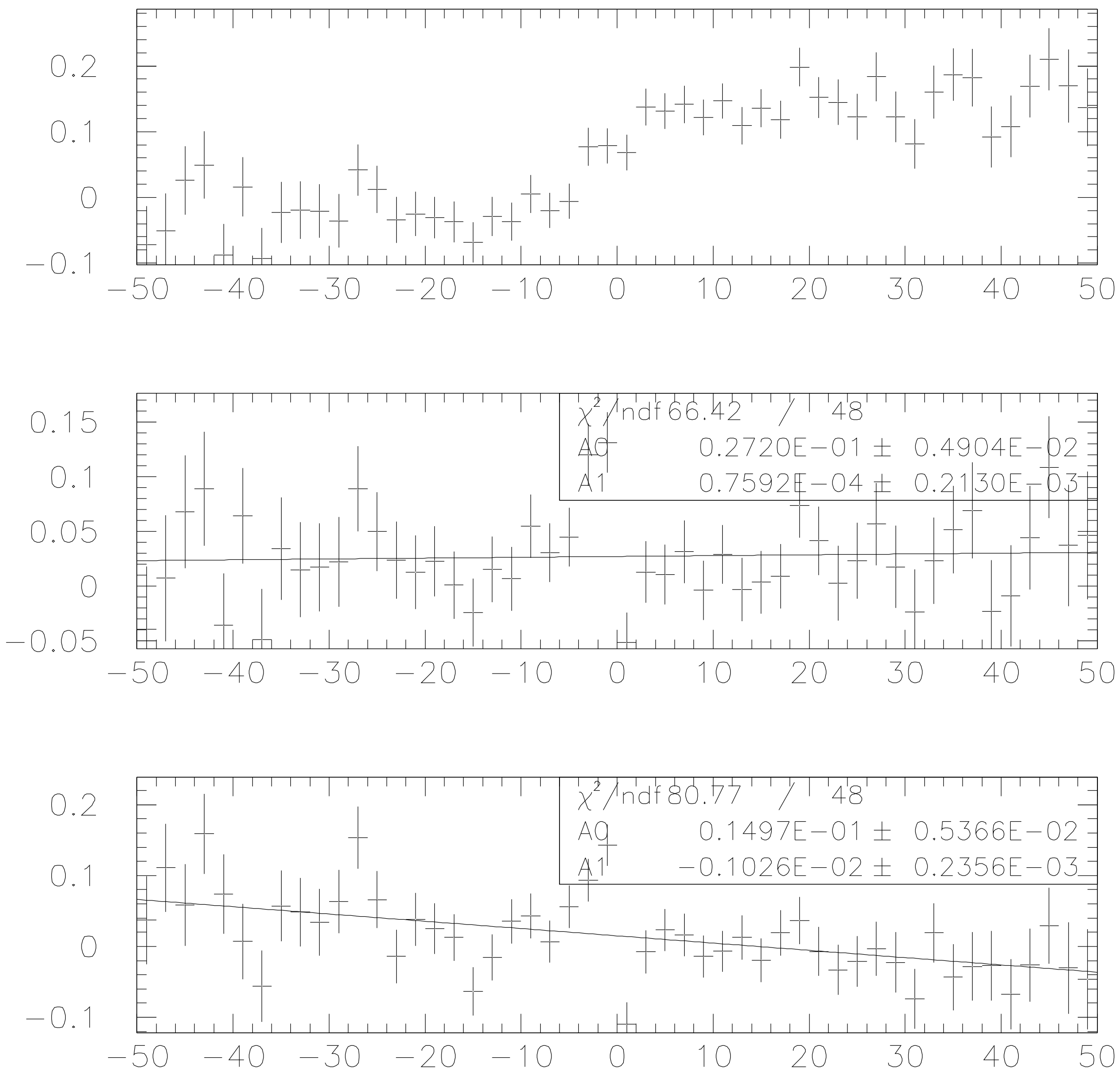
Mystery #3, continued

Black is old alignment; red is new alignment. Problem is much smaller after including endplate deflection, but we may be slightly overcorrecting.



Mystery #3, continued

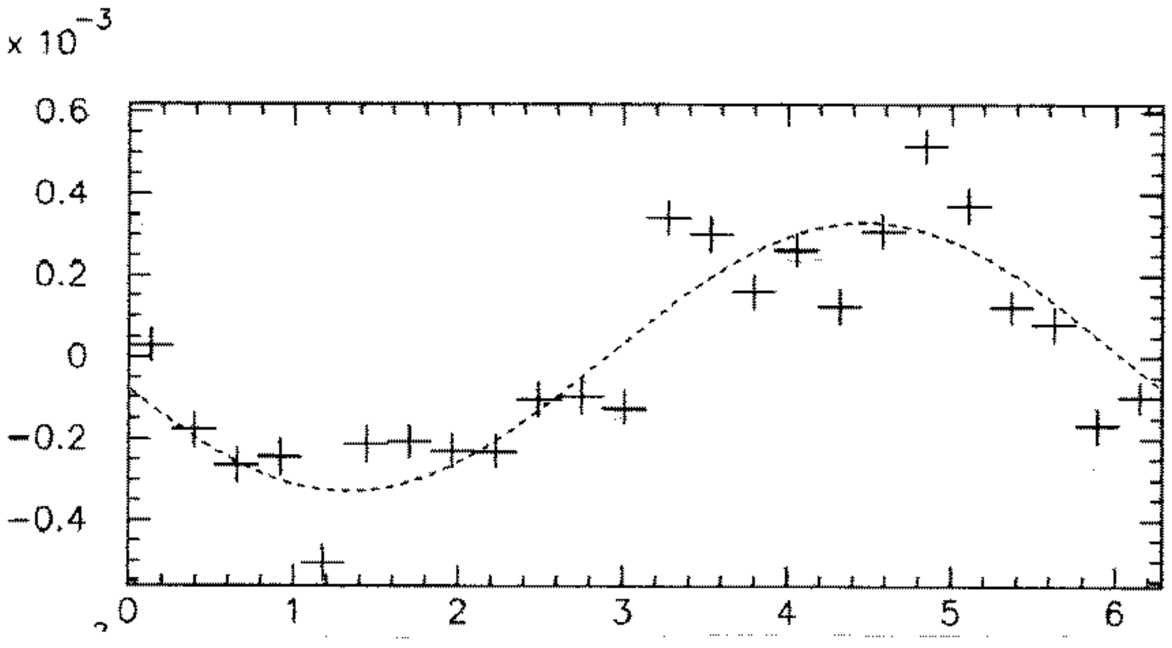
(Top) $\langle z_{\mathbf{CTC}} - z_{\mathbf{VTVZ}} \rangle$ vs $z_{\mathbf{VTVZ}}$ using old alignment. (Center) After hacking VTVZ to remove discontinuity. (Bottom) Using new alignment. Could it just be a bug or a wrong constant somewhere?



Mystery #3, continued

Is $\boldsymbol{E/p}$ asymmetry vs $\boldsymbol{\phi}$ due to global CTC/SVX offset?

$\left\langle \boldsymbol{q}\left(\frac{1}{p_T} - \frac{1}{E_T}\right)\right\rangle$ vs $\boldsymbol{\phi}$, after beam constraint, from $\boldsymbol{W}$ electrons.



Mystery #3, continued

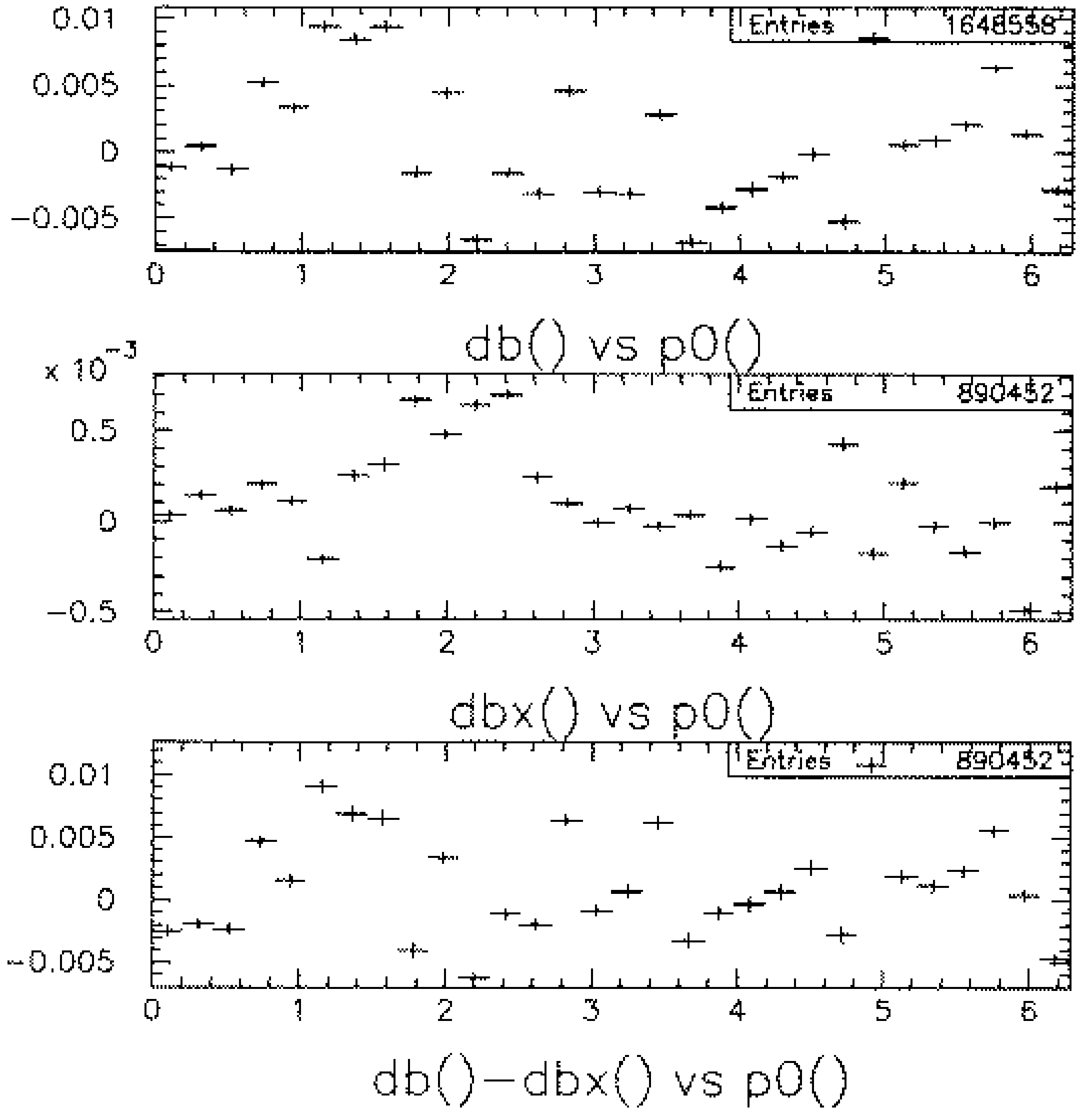


Figure 15: (Top) Mean CTC impact parameter (cm) with respect to SVX beamline vs. ϕ, from J/ψ data. (Center) Mean SVX impact parameter with respect to SVX beamline vs. ϕ. (Bottom) Difference between CTC and SVX impact parameters vs. ϕ. There is no obvious global SVX/CTC misalignment (which would appear as a sinusoidal offset of magnitude $\approx 60\ \mu$m), but CTC SL0 cell scatter makes it hard to say for sure.

Mystery #4: Fixed, Not Understood

Bad online calibration for inner superlayers. (Noticed by Alan Sill, 12/95.)

Alan found that hit usage on inner layers and resolutions on z_0, d_0, p_T(no BC) were improved substantially by iterating the run-by-run calibration procedure. In 12/97, new PRO and TMS constants were made by running through entire J/ψ sample.

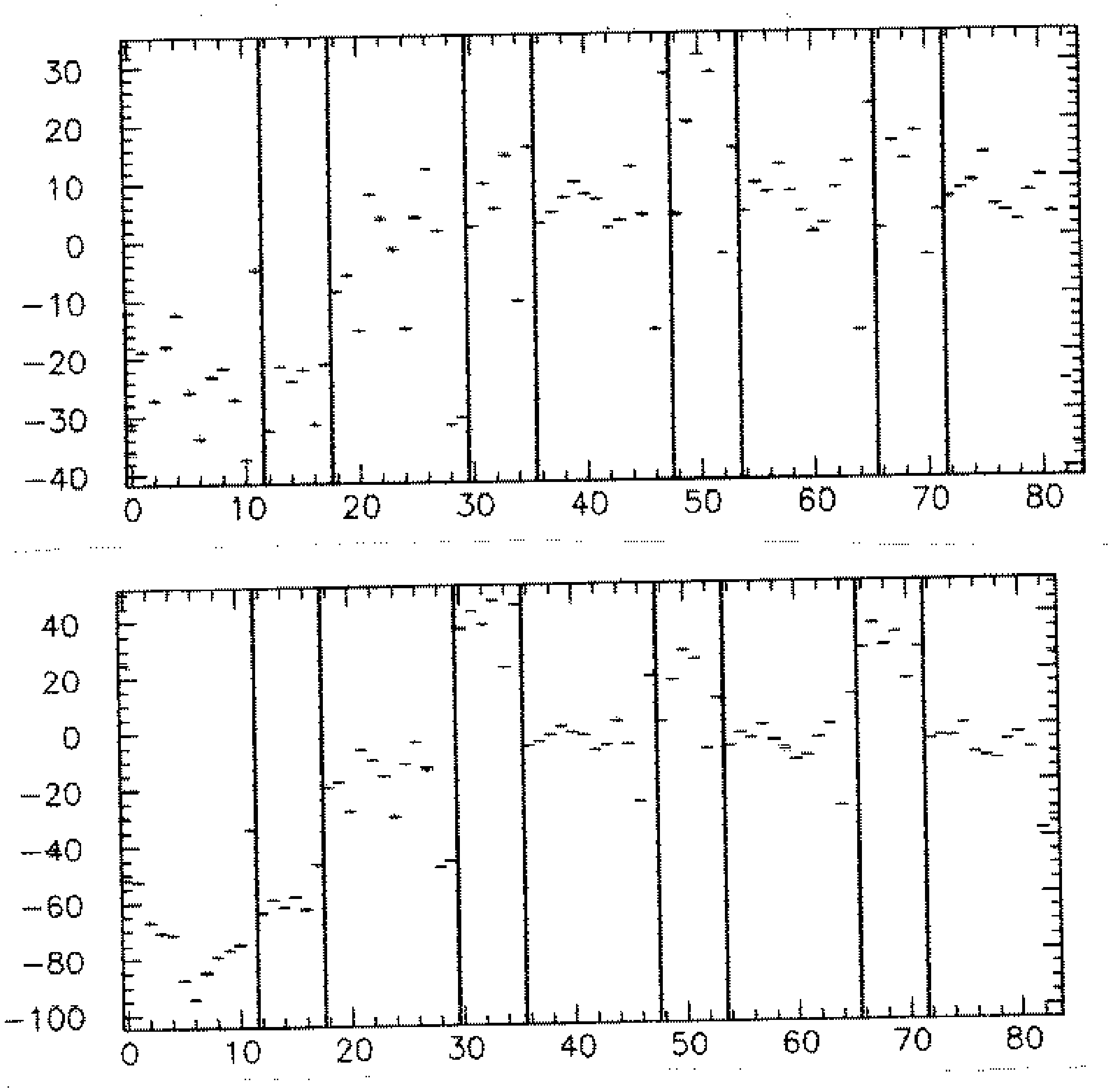
SL	0	1	2	3	4	5	6	7	8
before (μm)	265	210	205	210	172	220	170	158	157
after (μm)	214	176	193	186	170	220	167	154	156

parameter	before	after	improvement
d_0	570 μm	380 μm	35%
z_0	1.0 cm	0.65 cm	35%
$1/p_T$ (BC)	0.10 %/GeV	0.09 %/GeV	10%

Something unexpected is that the recalibration improved $\langle \Delta y \rangle$ vs layer, not just $\langle \Delta |D| \rangle$. It also resolved the mysterious fact that initially, the Run Ib WPO alignment constants looked inexplicably different from the Run Ia constants in the inner layers. (See next pages.)

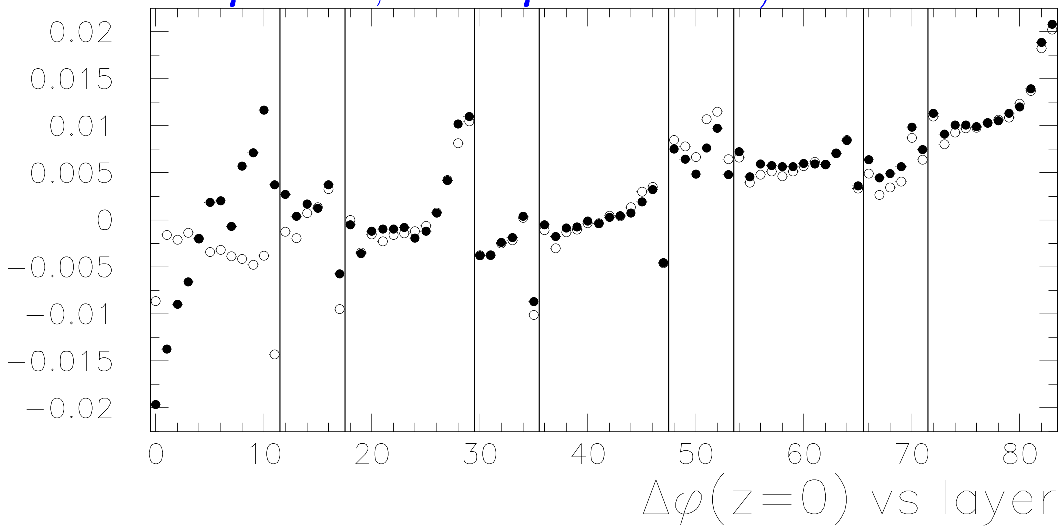
Mystery #4, continued

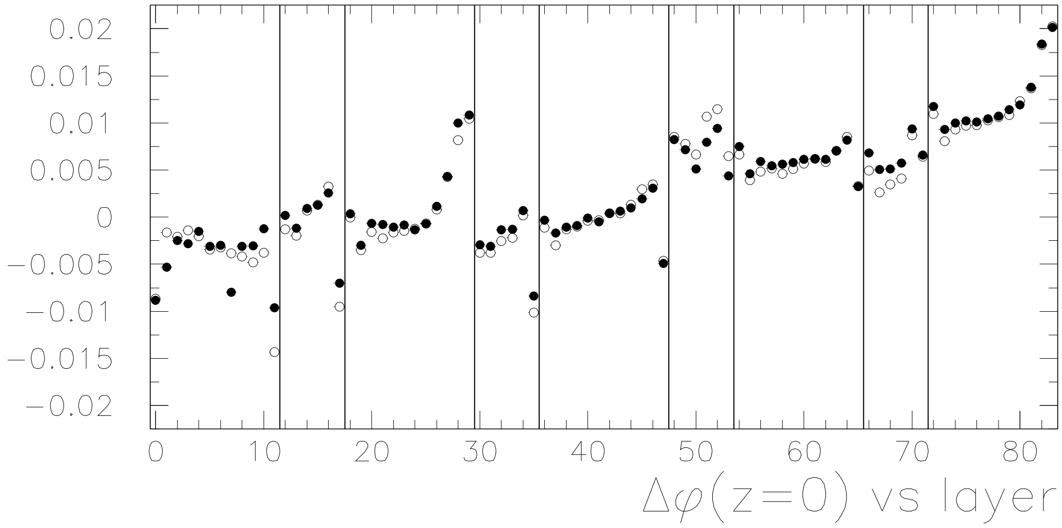
$\langle \boldsymbol{\Delta}|\boldsymbol{D}|\rangle$ vs layer, after (above) and before (below) recalibration, for $\boldsymbol{\mu}$ from $\boldsymbol{\psi}$ decay.



Mystery #4, continued

WPO alignment offsets $R_i\Delta\varphi$ vs layer (Ia vs Ib), before (above) and after (below) Ib PRO/TMS drift-model recalibration. Effect of drift model on "alignment" constants was unexpected. (Note labeling error: y axis is $R\Delta\varphi$ in cm, not $\Delta\varphi$ in radians.)

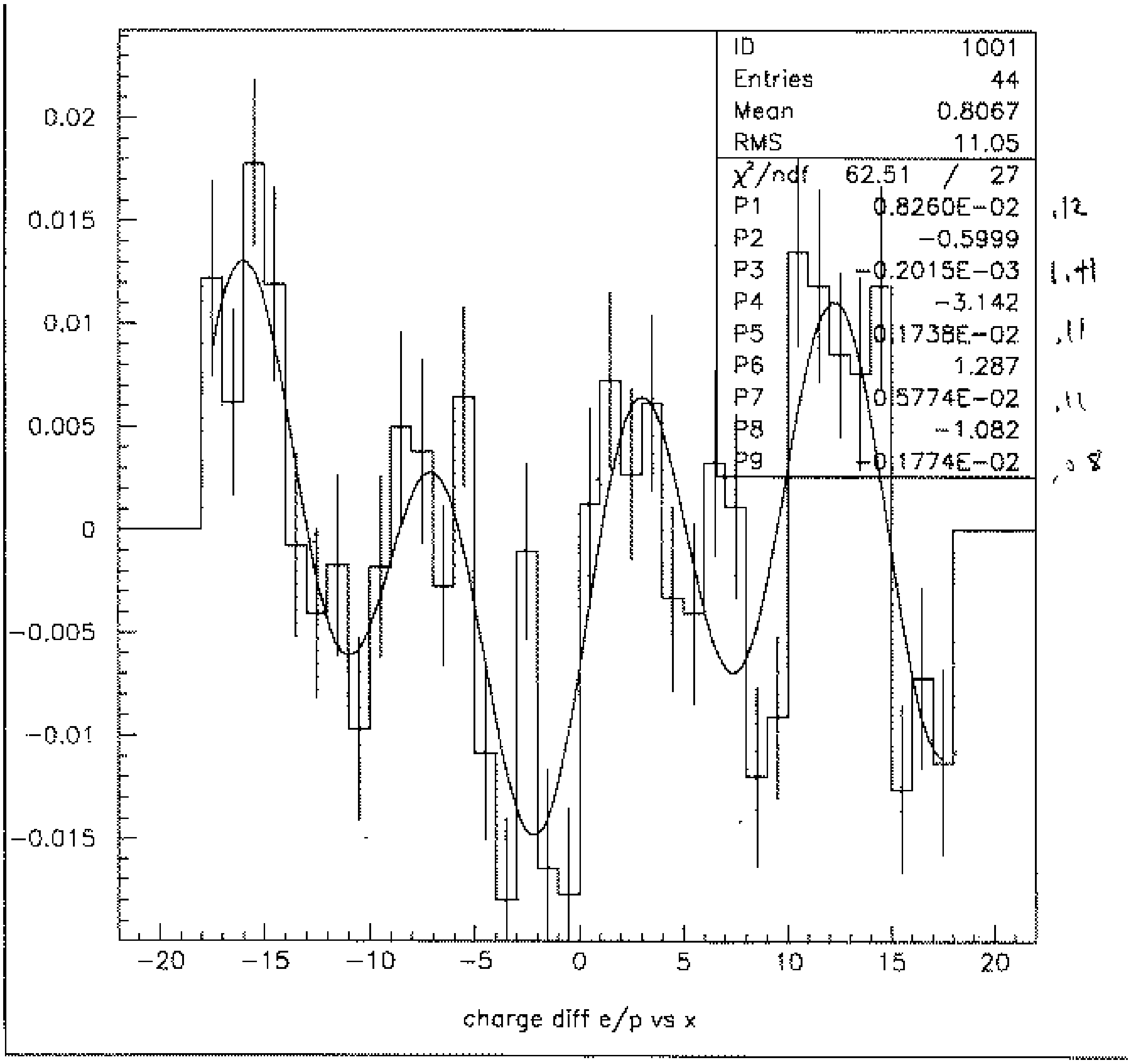




Mystery #5: Unsolved

$\boldsymbol{E/p}$ shows SL8 cell structure

Larry Nodulman has been pointing this out for years. Looking at $\boldsymbol{E/p}$ $+$ vs $-$ in a CEM cell ($\boldsymbol{2\pi/24}$ in azimuth) shows $\sim$ 1% wiggles with SL8 cell spacing period ($\boldsymbol{2\pi/120}$).



CTC 1b

from Larry's straw alignment talk

Mystery #6: The Big One

E/p peak fit gets Z mass wrong by nearly $1/2\%$

- Generate $W \to e\nu(\gamma)$, $Z \to ee(\gamma)$ with Berends-Kleiss etc.
- Take material distribution from γ conversion map, small corrections for radial efficiency, attenuation; normalize either to CTC inner cylinder (known radiator) or to $E/p > 1.4$ tail. Either way, electron traverses about $7.5\%\ X_0$ before CTC gas.
- Track e,γ through B field (calibrated to J/ψ mass), allowing bremsstrahlung and pair production, according to Tsai's 1974 formulas
  brem: $\frac{dN}{dy} = \frac{\#X_0}{y}((\frac{4}{3}+k)(1-y)+y^2), k \approx 3\%, y_{\min} = 0.001$
  conv: $\textbf{prob} \to \frac{7}{9}(\#X_0)$ at high E_γ
- Simulate CTC measurement with Gaussian smearing from 5×5 covariance matrix. (Hit patterns and resolutions from $W \to e\nu$ data; fudge factor to get $\sigma(E/p)$ right.) For brem within CTC, average helices before and after with respective weight matrices.
- Trace particles to CEM. Neglect coil ($1.1X_0$). Simulate tower structure. Assume every γ, however puny, adds linearly in CEM. CEM resolution from $Z \to ee$ fit.
- Float CEM energy scale until $\langle E/p \rangle_{0.9\text{–}1.1}$ agrees with simulation.
- Measure $Z \to ee$ lineshape; find data are $0.4 \pm 0.1\%$ low.
- While this simulation is naive, in 2.5 years since problem was discovered, nobody has been able to identify even an 0.1% effect.
- Many comparisons of $W \to e\nu$, $W \to \mu\nu$ track quality.

Mysteries of Xmas Past

A few assorted mysteries (solved) from Run Ia and earlier

- inner detector material count from Run Ia $\boldsymbol{E/p}$ tail disagreed by $\sim$ 30% with $\boldsymbol{W}$ mass simulation based on geometry DB

  $\boldsymbol{E/p}$ confirmed with photon conversions (CDF 2899, Barry)

- $\boldsymbol{B}$ field non-uniformities were neglected, until they appeared in $\boldsymbol{M(\psi)}$ vs $|\boldsymbol{z(\mu)}|$ as part of Ia $\boldsymbol{M_W}$ measurement

- the fact that a sense wire sag of $\mathbf{250}\ \boldsymbol{\mu}\mathbf{m}$, used in the early code, differed from the actual $\mathbf{230}\ \boldsymbol{\mu}\mathbf{m}$ sag was found in Run 0 data

Thoughts for Run II

It will be useful if some details of the fitting are accessible from user code, so that people analyzing data can easily check the quality of their tracks. At a minimum, track residuals should be accessible to mere mortals. (Looks promising.)

If CTC hits had been routinely available last run (which would have required a better CDF data-handling system), we would have identified and fixed CTC problems much earlier. (Looks promising: COTD in PADs.)

It may be useful if structure of final fit makes it easy to tinker with, so that possible improvements—in response to new mysteries—can be tried out quickly and accepted or rejected. (Currently it is pretty easy.)

Choice of parameters in alignments and calibrations is important. Input from detector construction is needed to decide what to fix/float when things are inconsistent in the data. (Commissioning run may be good practice.)