Local Polarimetry for Proton Beams with STAR ZDC Calorimeters

David Grosnick
Valparaiso University
for the STAR collaboration

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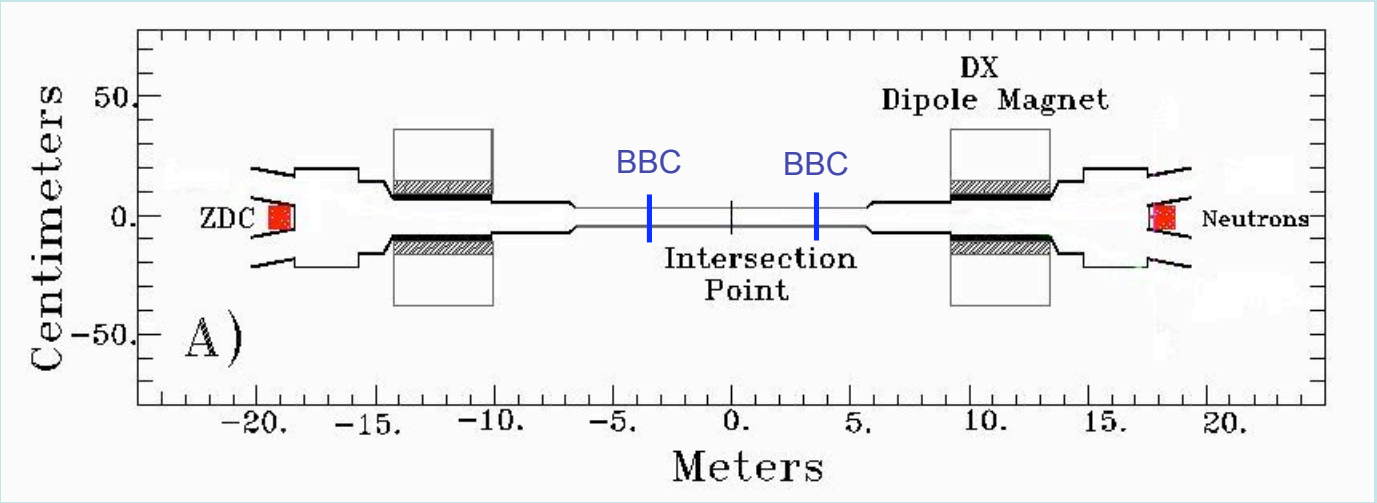
Local Polarimeters at STAR

- Currently, beam-beam counters used as local polarimeter at STAR for $\sqrt{s} = 200\ \mathrm{GeV}$
- At higher beam energies, BBCs may have decreasing analyzing power → insufficient polarization measurement
- Need detector located at larger distance from intersection point → Zero-Degree Calorimeters
- Detects forward (< 2 mrad) neutral particles



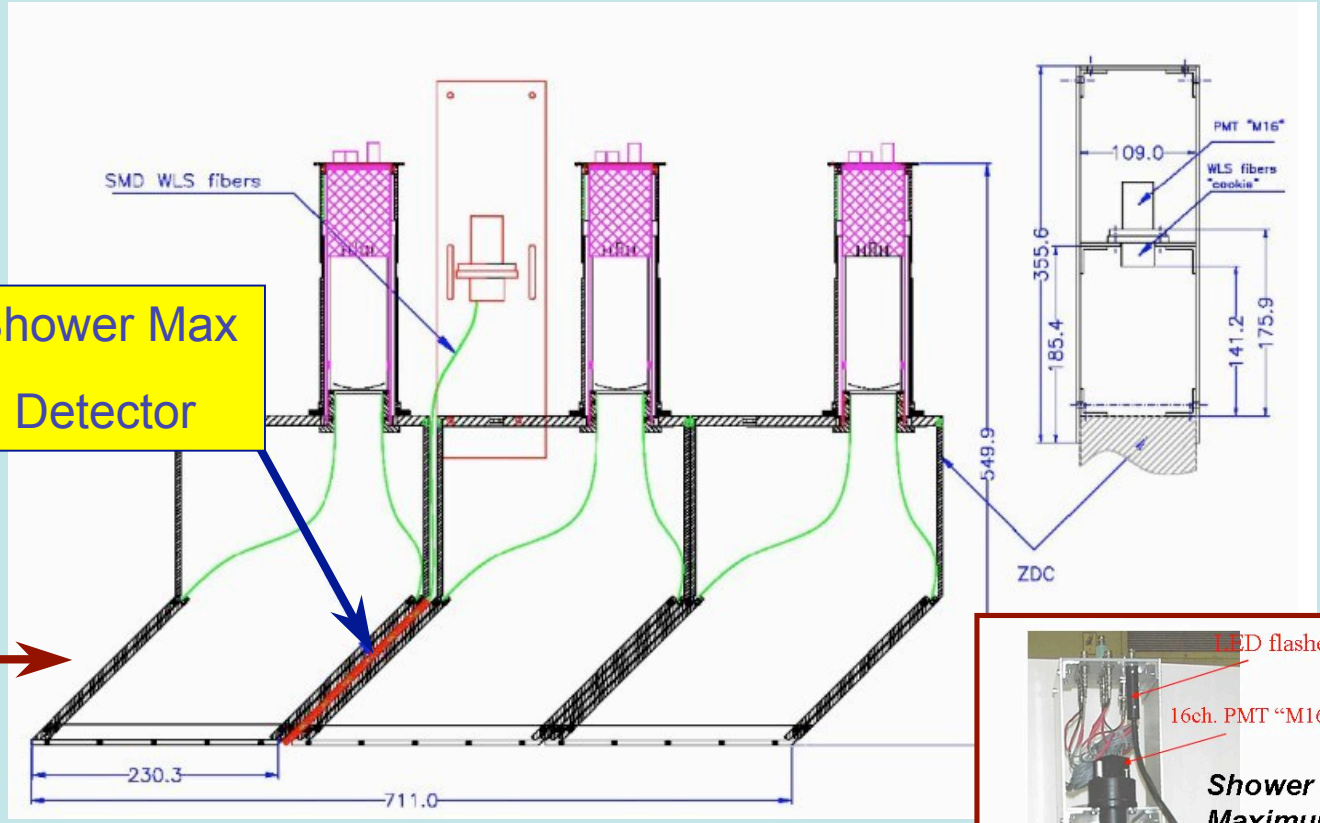
ZDCs

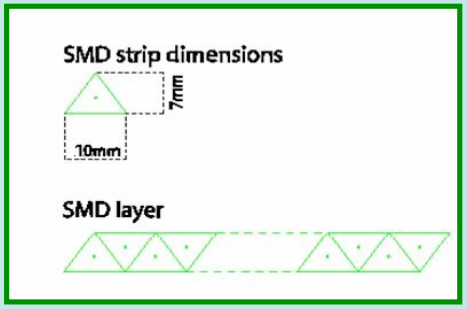
Zero-Degree Calorimeters (ZDC) at STAR

Sampling calorimeter

Shower Max Detector

Beam





Shower Max Detector

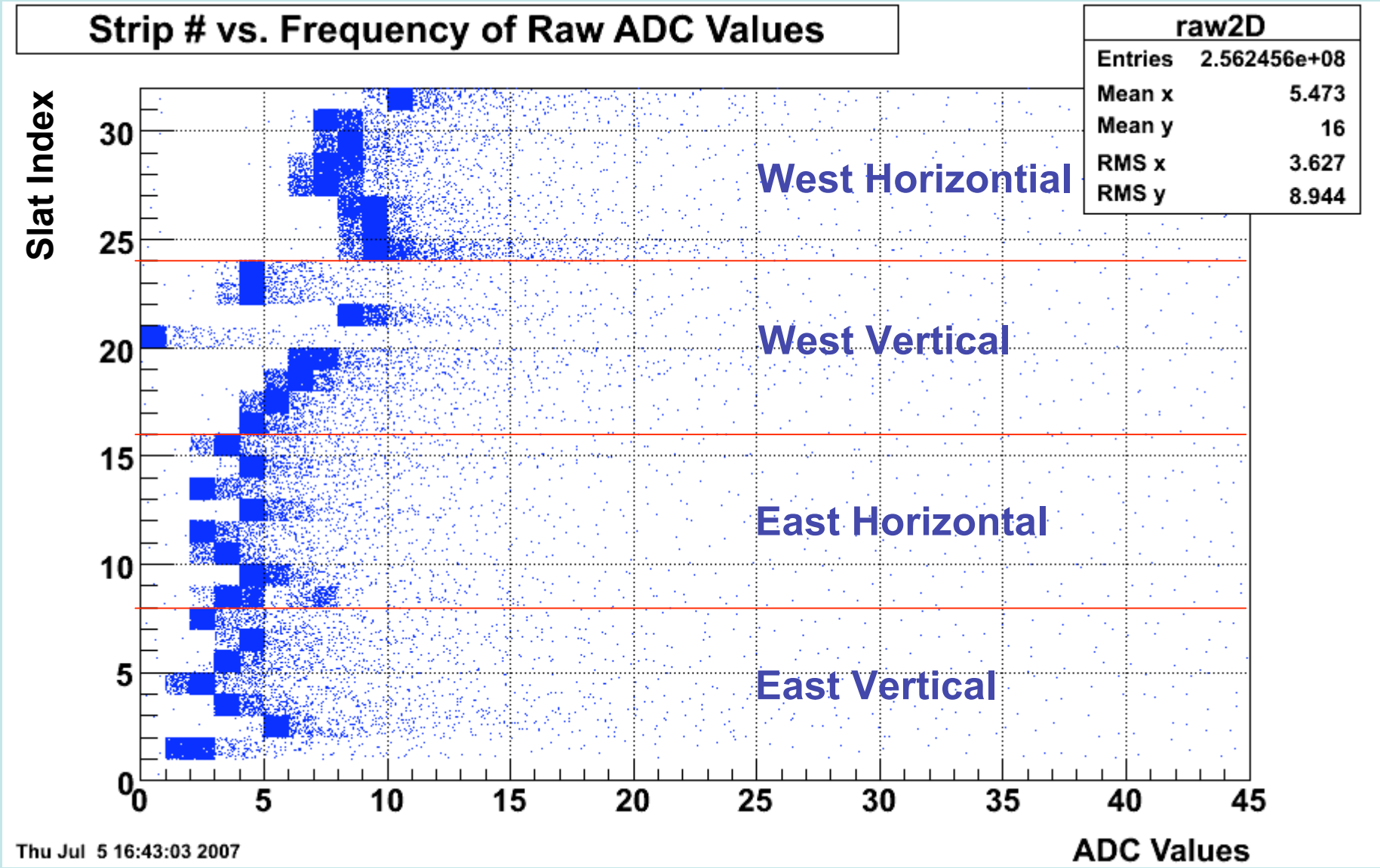
8 horizontal slats (4 strips)

7 vertical slats (3 strips)

Available Data from Dedicated Runs

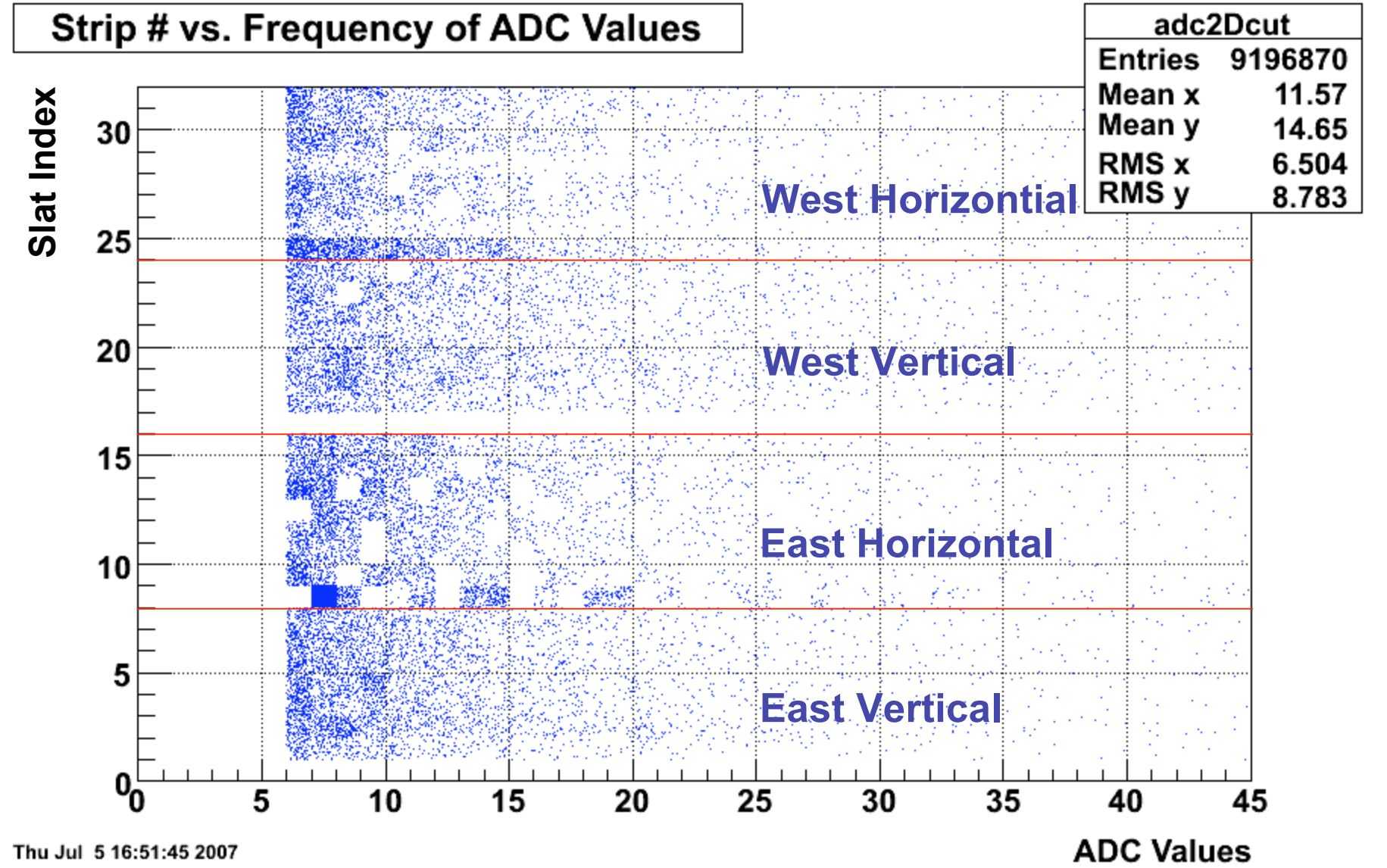
- Determine feasibility of using ZDC SMDs as local polarimeter
- Small data sample from limited no. dedicated runs
- Limited quality of data: not all spin states present and not all spin rotator states available
- Method: gain-match and pedestal-subtract ADC values from each vertical and horizontal SMD slat
- Good hits are used to calculate left-right and up-down asymmetries for beam spin states in each east and west ZDC
- Used square-root asymmetries

ZDC Shower Max Detector Data



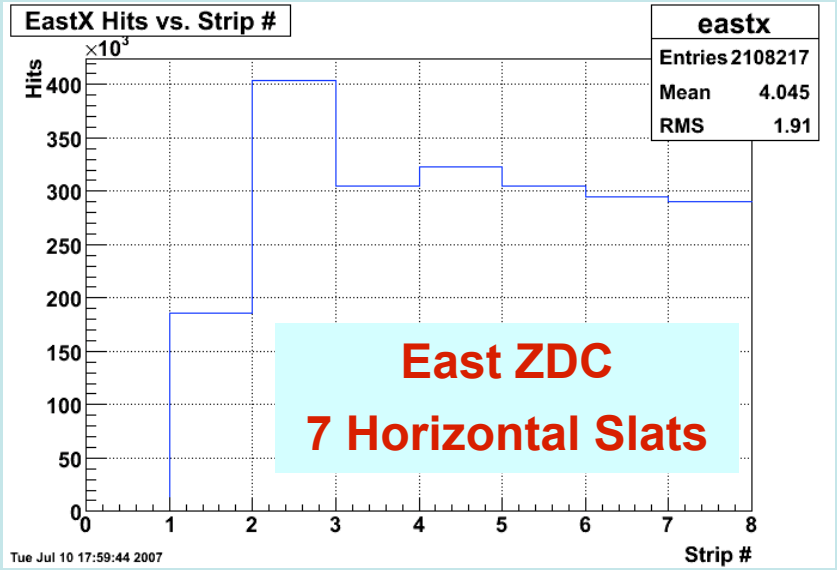
Plot of raw ADC values for given slat index

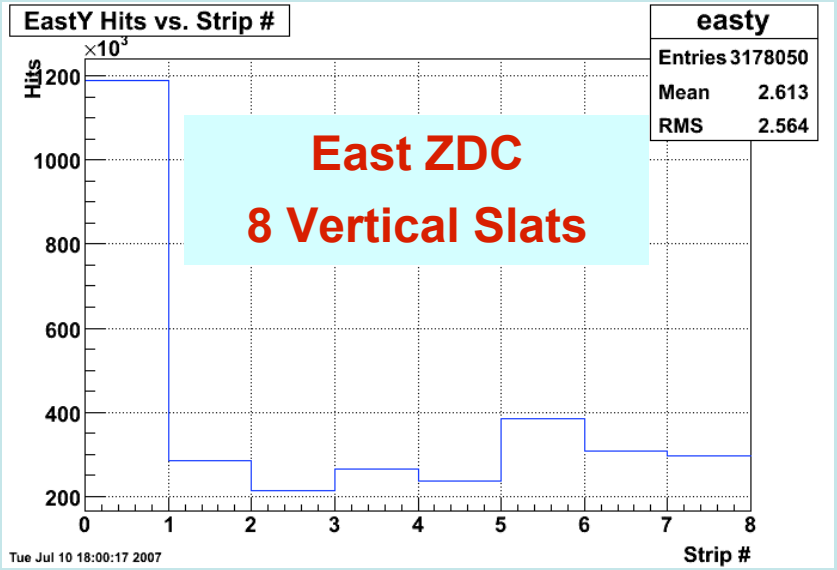
ZDC Shower Max Detector Data

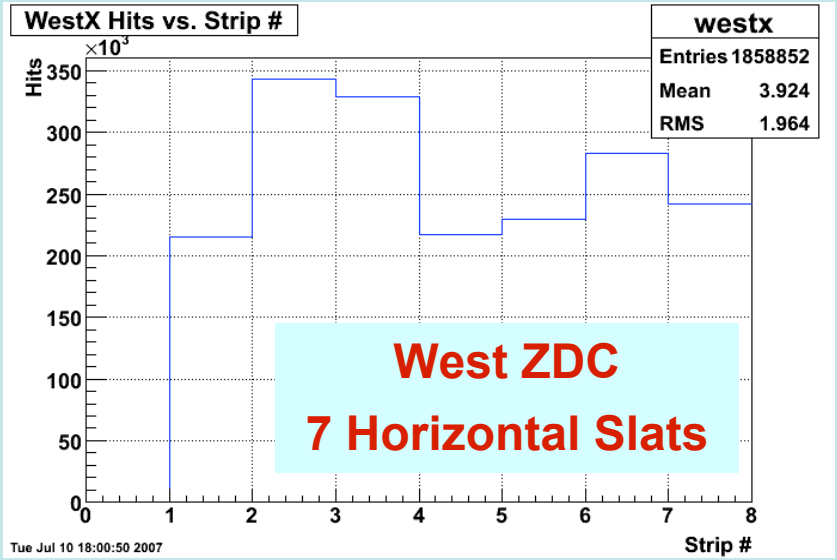


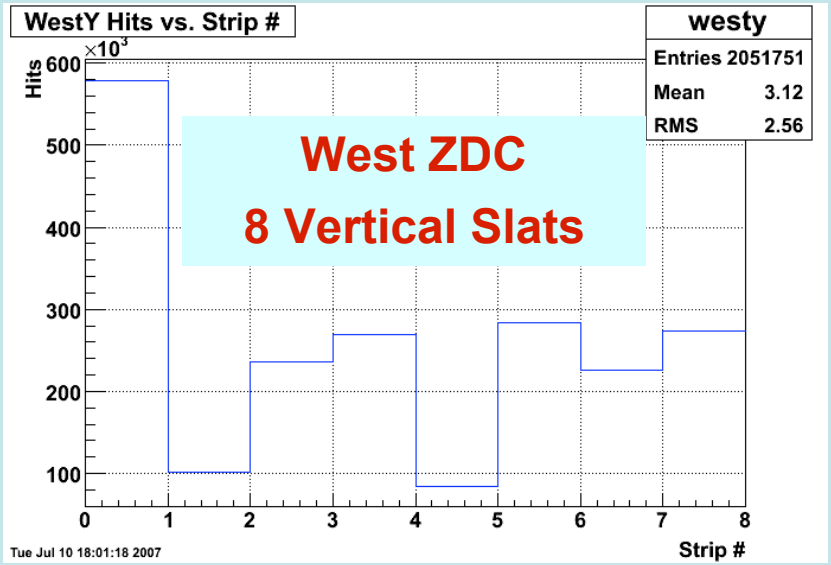
Plot of corrected ADC values for given slat index

SMD Hit Patterns – East and West ZDC

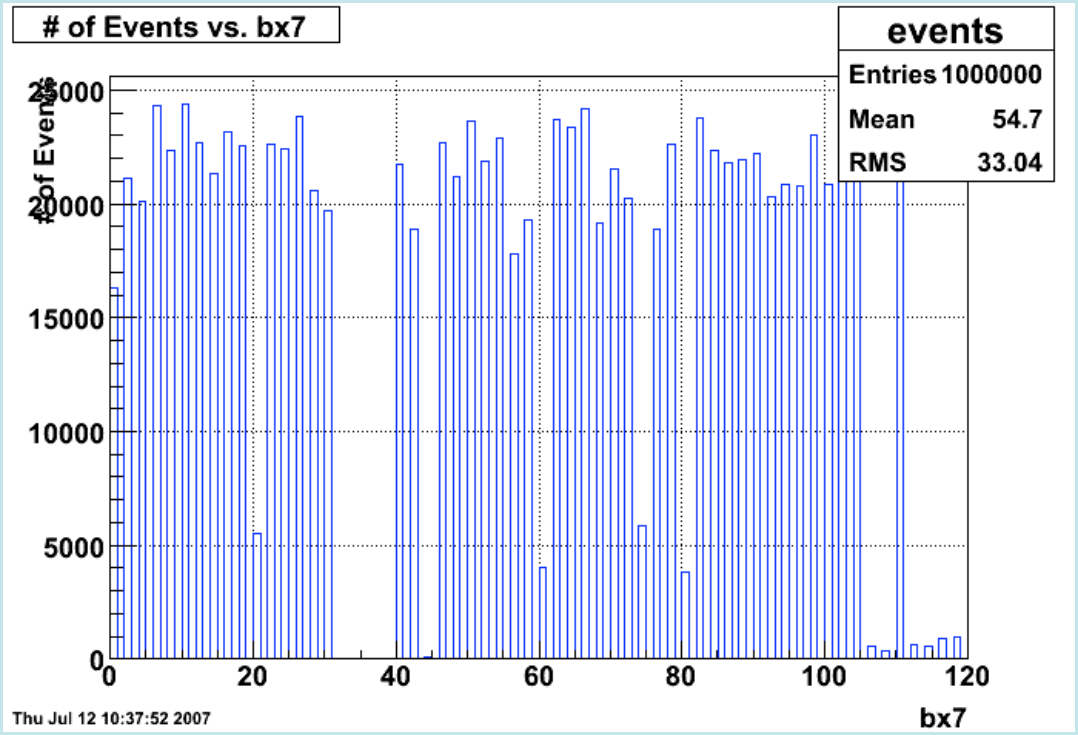








Spin Patterns in Bunches Per Spill



No. Events in ZDC per bunch crossing

Can still measure physics asymmetry with limited polarization states

Corrected spin patterns in bunch

Fill 5170 Shifted blue bunches by 32 later (80 earlier)

Bunch										1										2										3										4										5										6
No.	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
Blue	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.
Yellow	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.

Bunch	6							7								8								9								10								11								12							
No.	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
Blue	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.
Yellow	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.	+	.	-	.	.

Note: missing spin patterns

Physics Asymmetry Calculation

Calculated assuming that only 2 of 4 usual spin states are available

$$\varepsilon^{e}_{phys} = \frac{\sqrt{N^{\uparrow\uparrow}_{Le} N^{\downarrow\downarrow}_{Re}} - \sqrt{N^{\downarrow\downarrow}_{Le} N^{\uparrow\uparrow}_{Re}}}{\sqrt{N^{\uparrow\uparrow}_{Le} N^{\downarrow\downarrow}_{Re}} + \sqrt{N^{\downarrow\downarrow}_{Le} N^{\uparrow\uparrow}_{Re}}}$$

$$= \frac{P_Y A_{fe} - P_B A_{be}}{1 + P_Y P_B A_{NN,e}} + higher - order\ terms$$

where

$$P_Y = \tfrac{1}{2}(P_Y^{\uparrow} + P_Y^{\downarrow})$$

$$P_B = \tfrac{1}{2}(P_B^{\uparrow} + P_B^{\downarrow})$$

Average beam polarizations

$$A_{fe} = \tfrac{1}{2}(A_{Lfe} + A_{Rfe})$$

$$A_{be} = \tfrac{1}{2}(A_{Lbe} + A_{Rbe})$$

$$A_{NN,e} = \tfrac{1}{2}(A_{NN,Le} + A_{NN,Re})$$

Average analyzing powers and 2-spin parameter

Differences in beam polarizations (U,D) and analyzing powers (L,R) enter calculation as higher-order corrections

Calculated Asymmetries from ZDC SMDs

Used square-root asymmetries:

$$\epsilon_{lum} = \frac{\sqrt{N_L^{\uparrow} N_R^{\uparrow}} - \sqrt{N_L^{\downarrow} N_R^{\downarrow}}}{\sqrt{N_L^{\uparrow} N_R^{\uparrow}} + \sqrt{N_L^{\downarrow} N_R^{\downarrow}}}$$

$$\epsilon_{phys} = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

L,R = left, right

U, D = up, down

e,w = east, west;

$\uparrow, \downarrow$ = spins up, down

Luminosity Asymmetry:

LRe = -0.0911 +/- 0.0012

UDe = -0.0918 +/- 0.0013

LRw = -0.0986 +/- 0.0013

UDw = -0.0955 +/- 0.0012

Physics Asymmetry:

LRe = 0.0137 +/- 0.0012

UDe = 0.0049 +/- 0.0013

LRw = 0.0140 +/- 0.0013

UDw = -0.0039 +/- 0.0012

Slat-by-Slat Physics Asymmetry

Calculated assuming that only 2 of 4 usual spin states are available

$$\varepsilon^{e}_{phys,i} = \frac{N^{\uparrow\uparrow}_{Le,i} - R\,N^{\downarrow\downarrow}_{Le,i}}{N^{\uparrow\uparrow}_{Le,i} + R\,N^{\downarrow\downarrow}_{Le,i}}$$

$$= \frac{P_Y\,A_{Lf,i} - P_B\,A_{Lb,i}}{1 + P_Y\,P_B\,A_{NN,Li}} + \textit{higher-order terms}$$

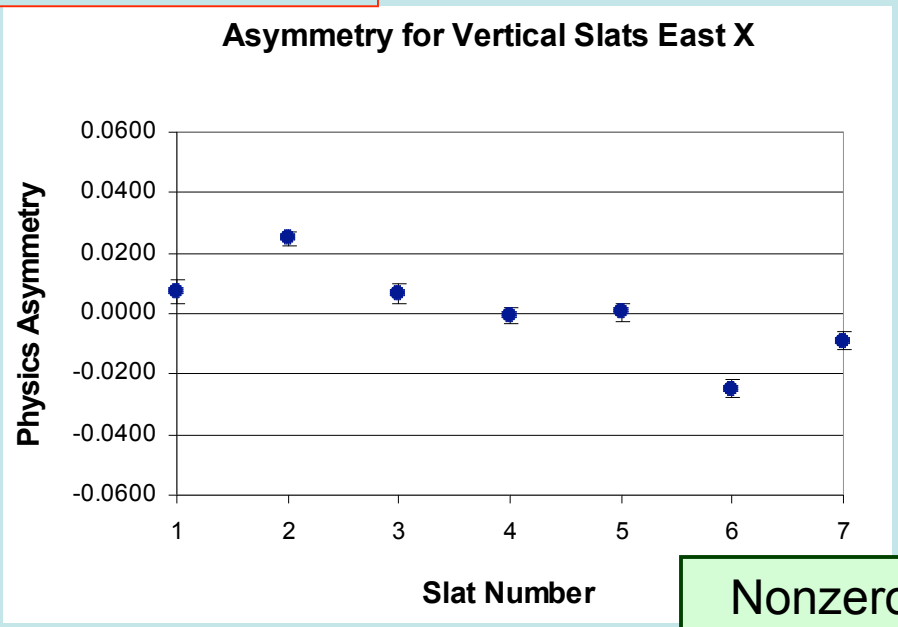
$$\approx \frac{N^{\uparrow\uparrow}_{Le,i}/L^{\uparrow\uparrow} - N^{\downarrow\downarrow}_{Le,i}/L^{\downarrow\downarrow}}{N^{\uparrow\uparrow}_{Le,i}/L^{\uparrow\uparrow} + N^{\downarrow\downarrow}_{Le,i}/L^{\downarrow\downarrow}}$$

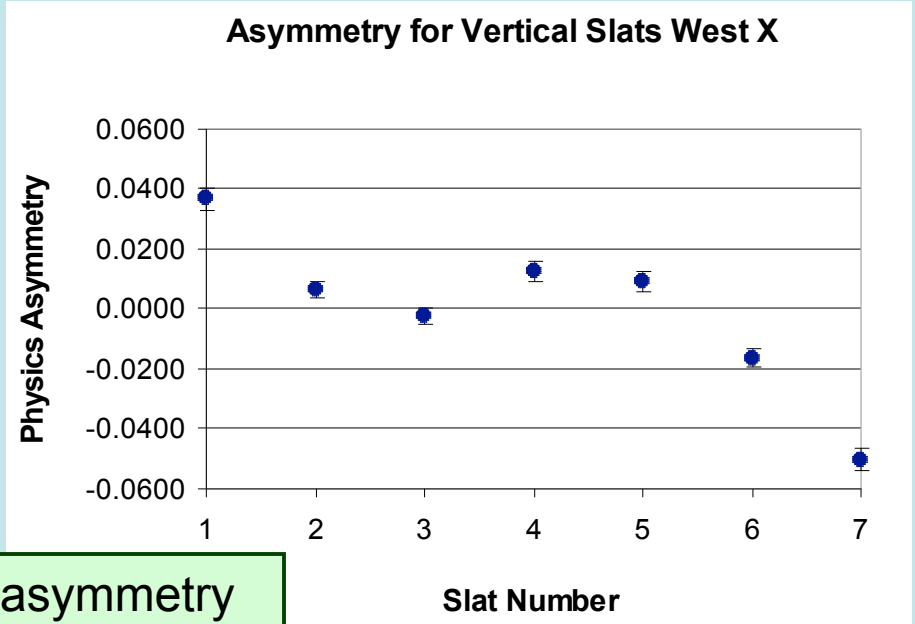
where $R = \dfrac{1 + \langle \varepsilon_{lum} \rangle}{1 - \langle \varepsilon_{lum} \rangle} \approx \dfrac{L^{\uparrow\uparrow}}{L^{\downarrow\downarrow}}$ Ratio of luminosities

Higher-order terms above are second-order in small quantities, rather than fourth-order in square-root asymmetry

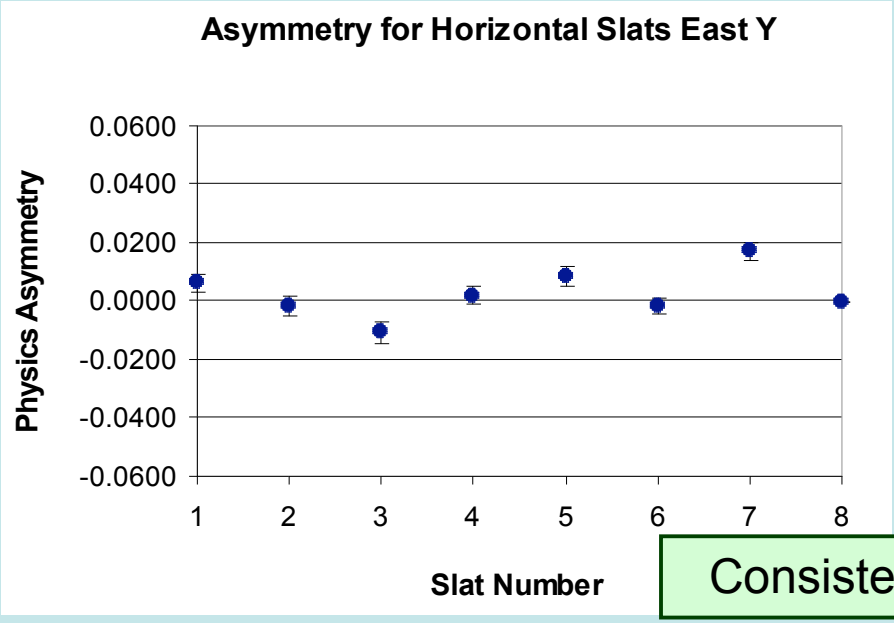
Individual Slat Asymmetries

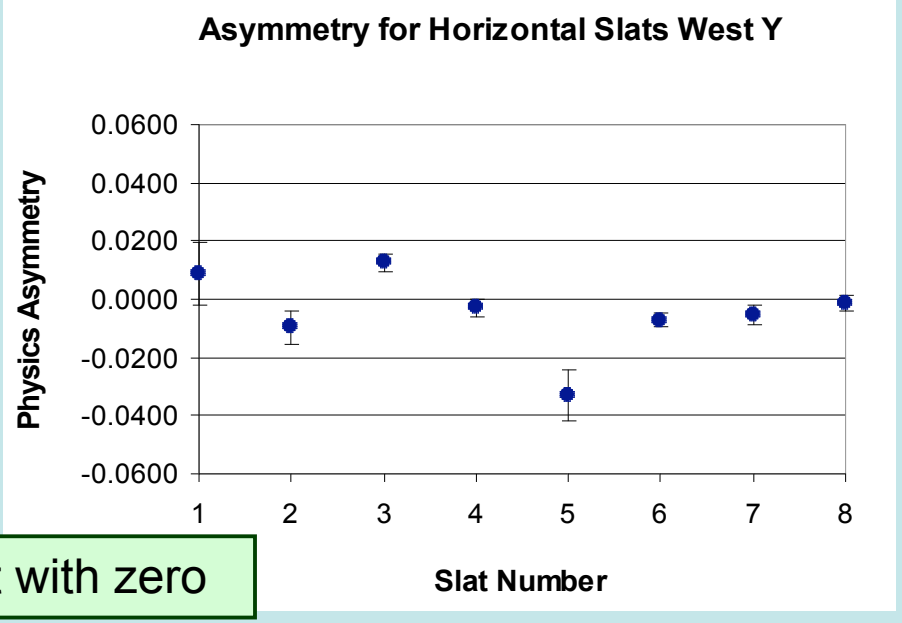
STAR Preliminary





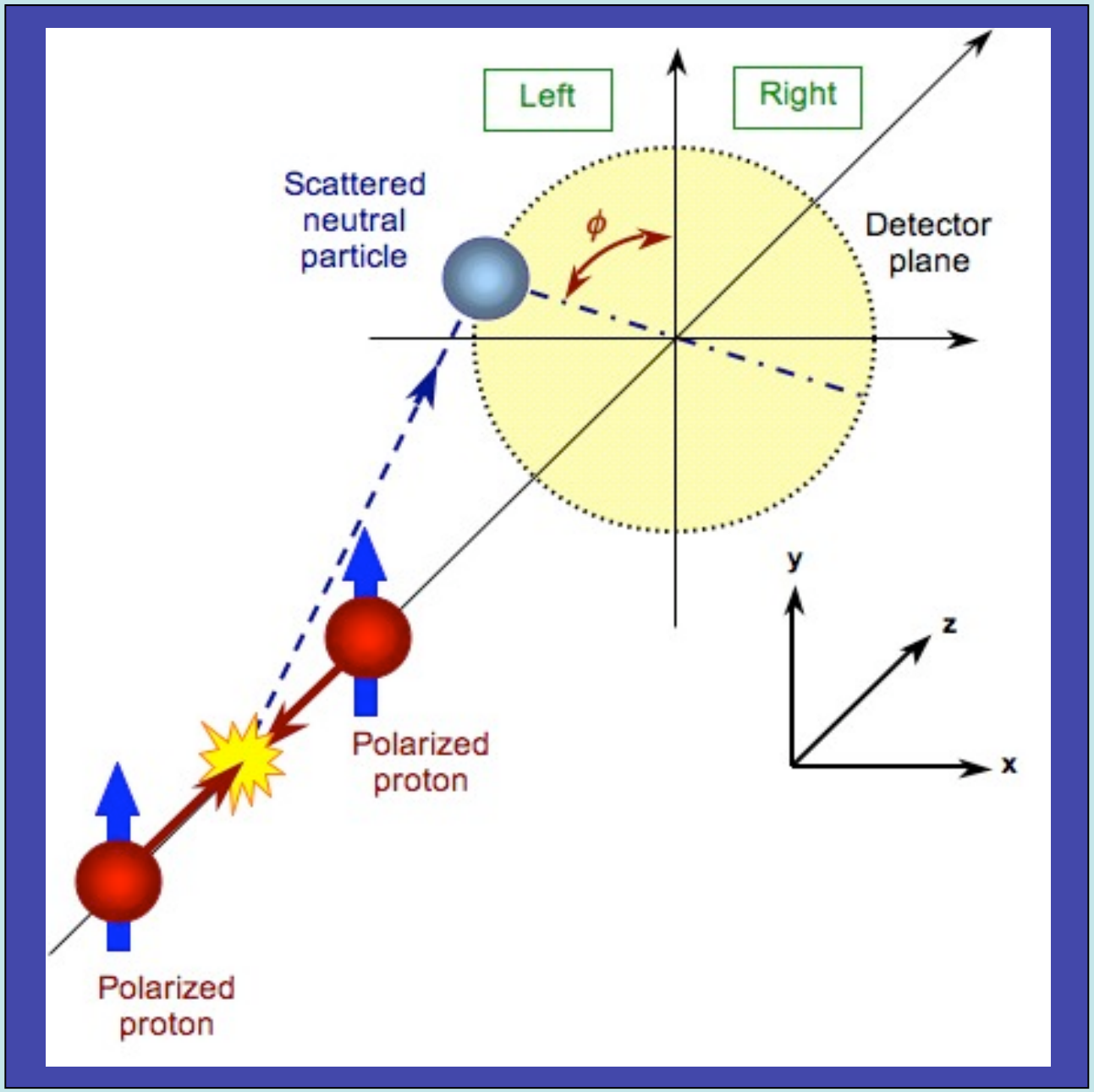
Nonzero asymmetry



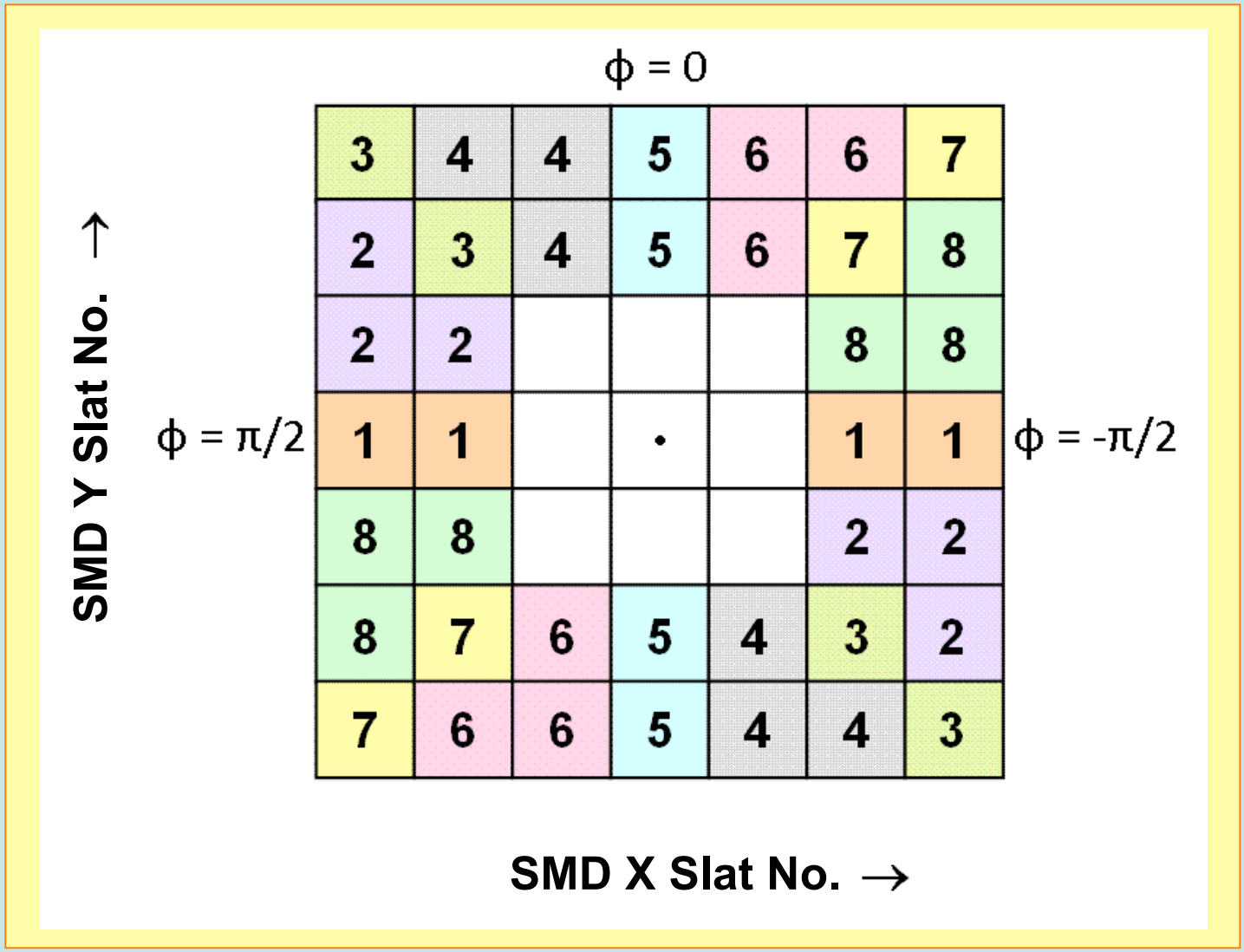


Consistent with zero

Definition of the Phi Asymmetry

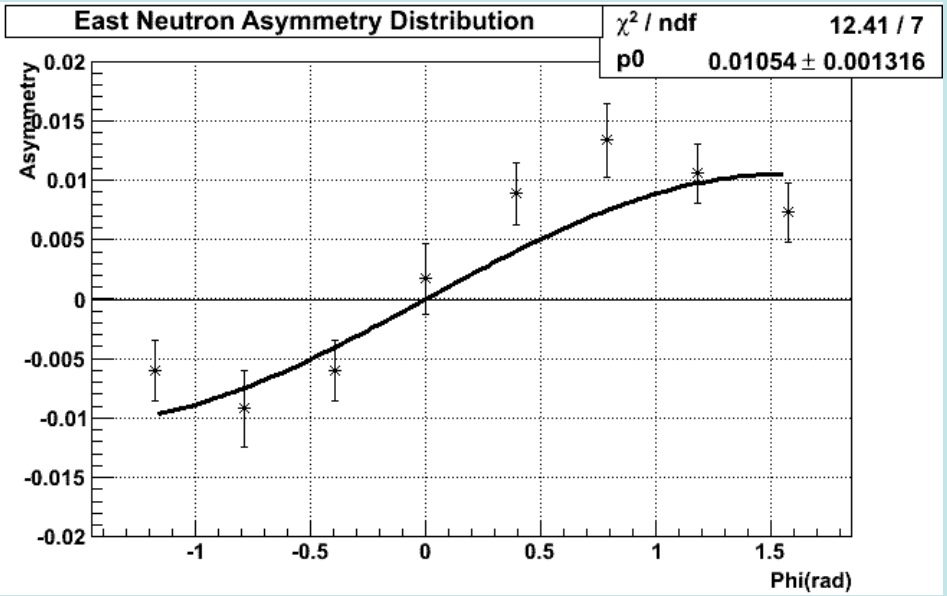


SMD Bin Map for Phi Asymmetry



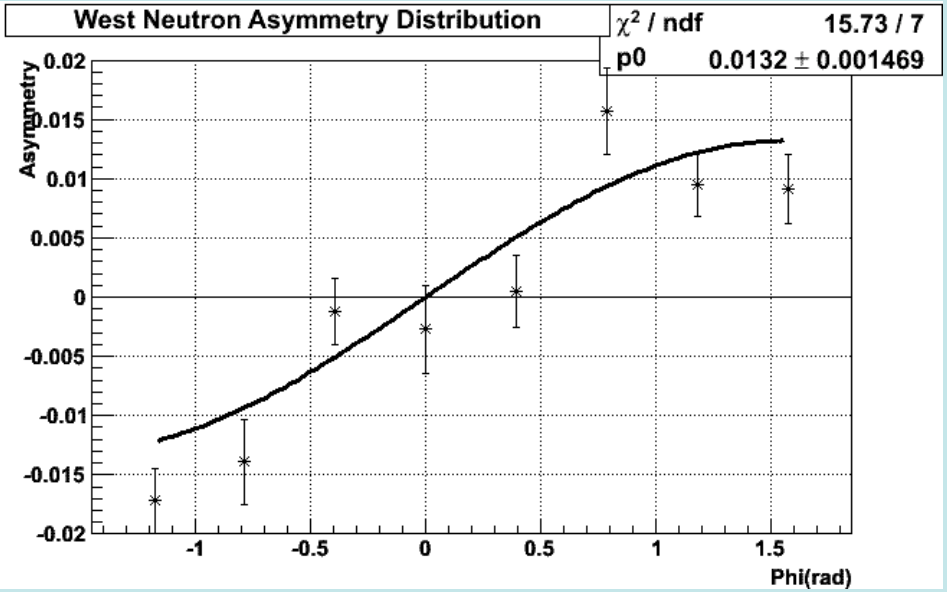
Form “left-right” asymmetries from opposite bins as function of angle ϕ

Phi Asymmetry of Neutral Particles



East ZDC Phi Asymmetry Distribution

STAR Preliminary



West ZDC Phi Asymmetry Distribution

Asymmetry of sum of vertical and horizontal slats for given SMD bin

Summary

- ZDCs tested for feasibility as local polarimeter at STAR
- Limited data sample analyzed using dedicated runs
- Results:
  - Observe significant L-R physics asymmetry
  - Small U-D asymmetry - consistent with beam proton spins both up or down
  - Results similar to other experiments
- Future: need further studies at high energies