Relative Luminosity: False Double Spin Asymmetries From a Transverse Asymmetry A_N

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Introduction to Relative Luminosity Systematic Uncertainty

- *Ratio* of luminosity between differently polarized bunches
  - As measured by a detector like the BBC
- Systematic uncertainty taken from comparison of Rel Lumi as measured by our BBC vs. ZDC
  - Hope different detectors sampling different physics processes aren't biased in the same way

Run	σ_{stat} π^0 A_{LL} smallest uncert. p_T bin	σ_{syst} RL
05, 200 GeV	13e-4	2.5e-4
06, 200 GeV	8.2e-4	7.5e-4
09, 200 GeV	8.2e-4	14e-4
11, 500 GeV	?	~5e-4

Definitions

Relative luminosity

$$R \equiv \frac{N_{BBC}^{++}}{N_{BBC}^{+-}} \text{ or } \equiv \frac{(\epsilon_N \epsilon_S \lambda)^{++}}{(\epsilon_N \epsilon_S \lambda)^{+-}}$$

$$r = \frac{(\epsilon_N \epsilon_S \lambda)_{ZDC}}{(\epsilon_N \epsilon_S \lambda)_{BBC}}$$

Ratio to compare ZDC, BBC

$$r_i = c(1 + S_b S_y \epsilon_{LL})$$

Bunch-fitting formula

$$\epsilon_{LL} = P_b P_y A_{LL}$$

“Raw” asymmetry

More Definitions

$$A_{LL} = \frac{(\sigma^{++} + \sigma^{--}) - (\sigma^{+-} + \sigma^{-+})}{(\sigma^{++} + \sigma^{--}) + (\sigma^{+-} + \sigma^{-+})}$$

$$A_{PV} = \frac{\sigma^{++} - \sigma^{--}}{\sigma^{++} + \sigma^{--}} \qquad A_{180} = \frac{\sigma^{+-} - \sigma^{-+}}{\sigma^{+-} + \sigma^{-+}}$$

$$A_{LL}^{++to+-} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$A_{LL}^{--to-+} = \frac{\sigma^{--} - \sigma^{-+}}{\sigma^{--} + \sigma^{-+}}$$

For **longitudinal** spin

Short Intro to our Hypothesis

- We suspect that a transverse component to the beam polarization...
  - Plus an A_N in forward neutron production
  - Plus beam angles or offsets
- ...is causing the asymmetry between our ZDC and BBC in longitudinal running
- We (PHENIX) want to do a 5 fill beam study in Run12 p+p 200 GeV to directly test this hypothesis

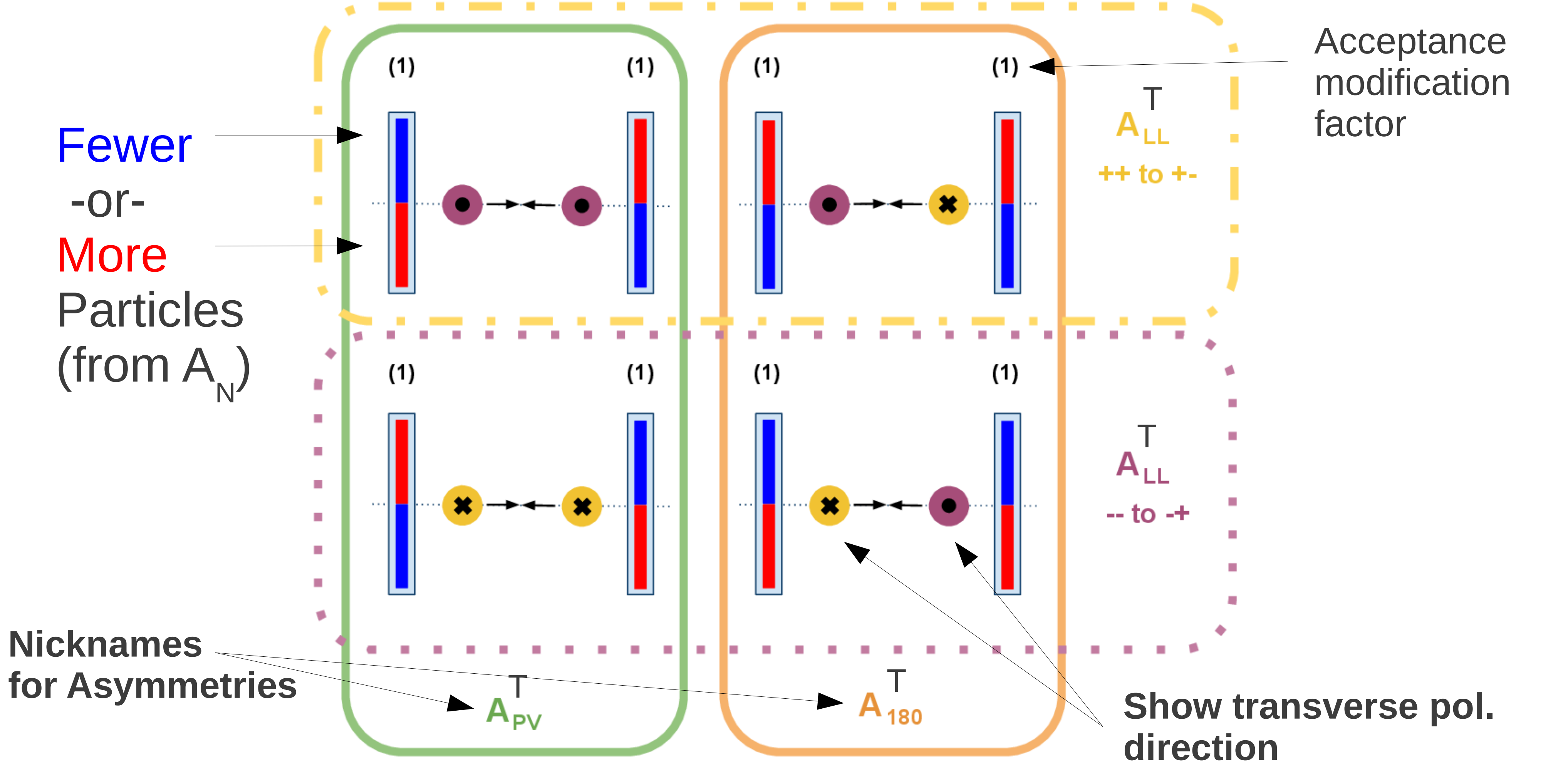
Outline

- I'm going to show the same thing in 3 different ways
  - Simple Model of Effect
    - I'll work through the math
  - Simulation Results
    - From TOY MC
  - Real Data: Run11, then Run09
- 4th way planned for future:
  - Beam study in Run 12, 200 GeV transverse
    - (to start!)

Simple Model

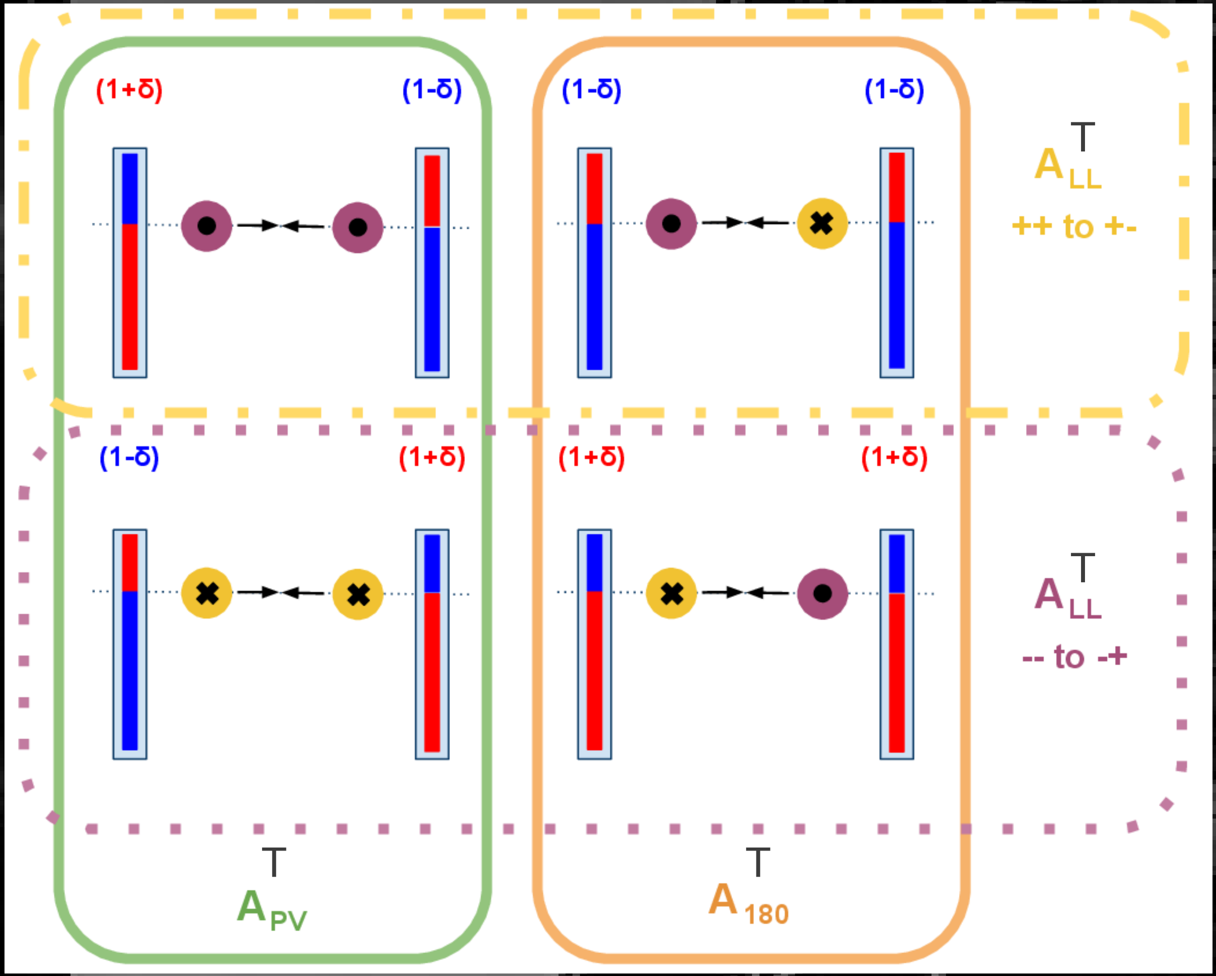
- Transversely polarized beams
- Beam offsets, boosts, and angles effectively modify the “left” vs. “right” geometrical acceptances of a detector
  - Important if there is an A_N
- Factor $a(1+\delta)$ or $a(1-\delta)$ (explained later) for an increase or decrease in **overall** acceptance

Simple Illustrated Model



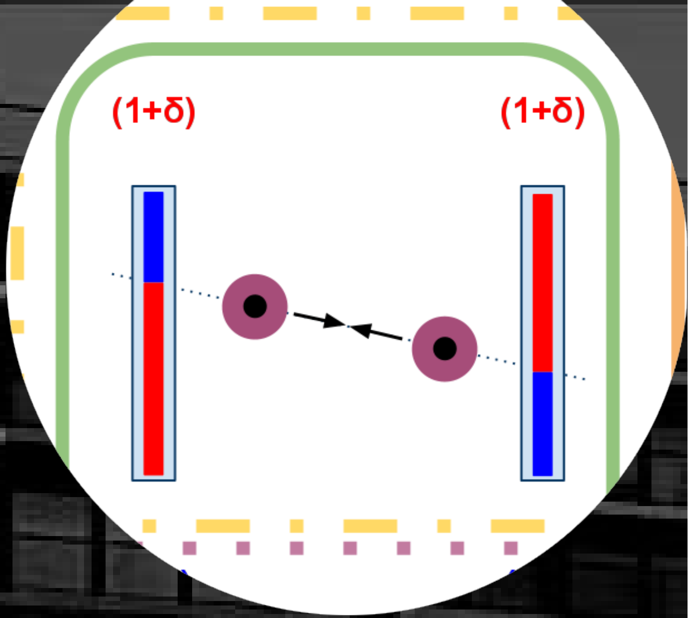
- Transversely polarized beams colliding, axis intersects middle of detectors

Beam Offsets



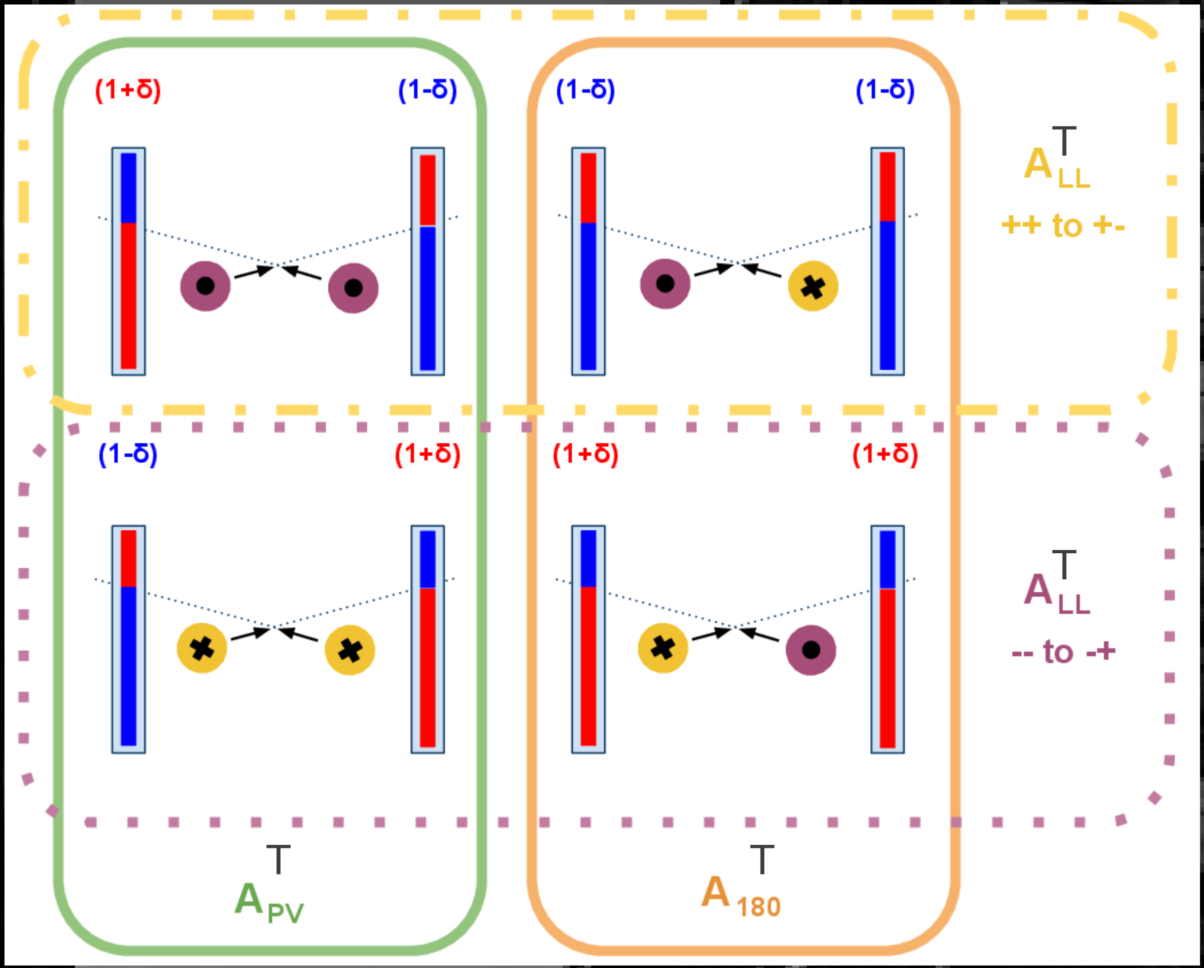
- Beam offset modifying left vs. right geometrical acceptance of detector
- With an A_N this effectively modifies overall acceptance of **EACH ARM** of the detector to **a(1+δ)** or **a(1-δ)** (explained on next slide)

Why a(1±δ)?



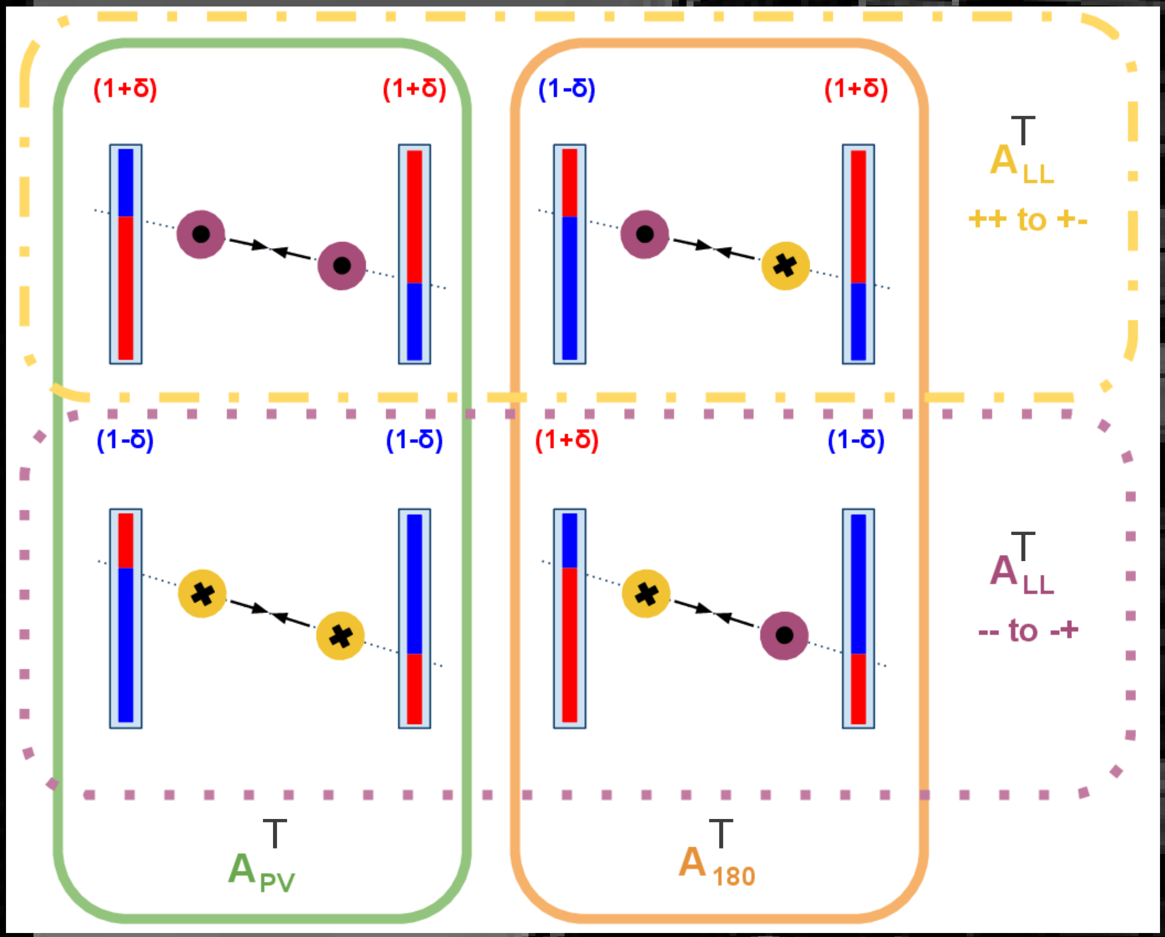
- Just simple redefinition to make math simpler, in terms of a single small parameter
- With beam on nominal center of detector:
  - **N** counts
- With beam moved “left,” lose from left and gain from right:
  - **N** – (**nL** – **nR**) = **N - n**
- With beam moved “right,” gain from left and lose from right:
  - **N** + (**nL'** – **nR'**) = **N + n'** (not necessarily same as **n**)
- Simple redefinitions as a(1-δ), a(1+δ) with
  - **a** = **N** + (1/2)*(**n'** - **n**), **a**δ = (1/2)*(**n'** + **n**)
- **a** will “cancel” in numerator and denominator when calculating asymmetries
- δ is a **single small parameter**

Transverse CM “Boost” (i.e. non-collinear angles)



- Similar effect to beam offsets
- 1 mrad angle like a **0.14 cm** offset on the BBC
- 1 mrad angle like a **1.8 cm** offset on the ZDC ---> effect of angle on ZDC ~10x BBC

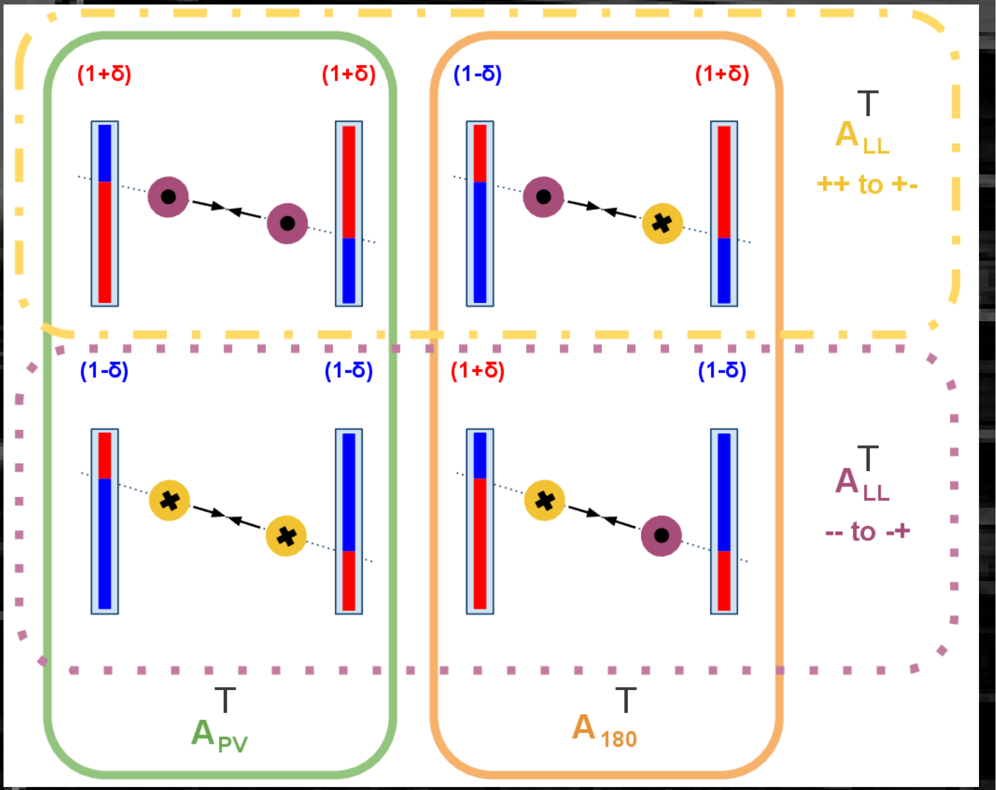
collinear Beam Angles



- Notice difference from offset in (1±δ) dependence (i.e. now contributes to A_{PV})

Generating Double Spin Asymmetries

- e.g.: parity violating asymmetry A_{PV} (++ vs. --) with collinear beam angles
- Assume
  - north and south detectors the same
  - only ZDC affected
  - no actual double spin asymmetry (just A_N)



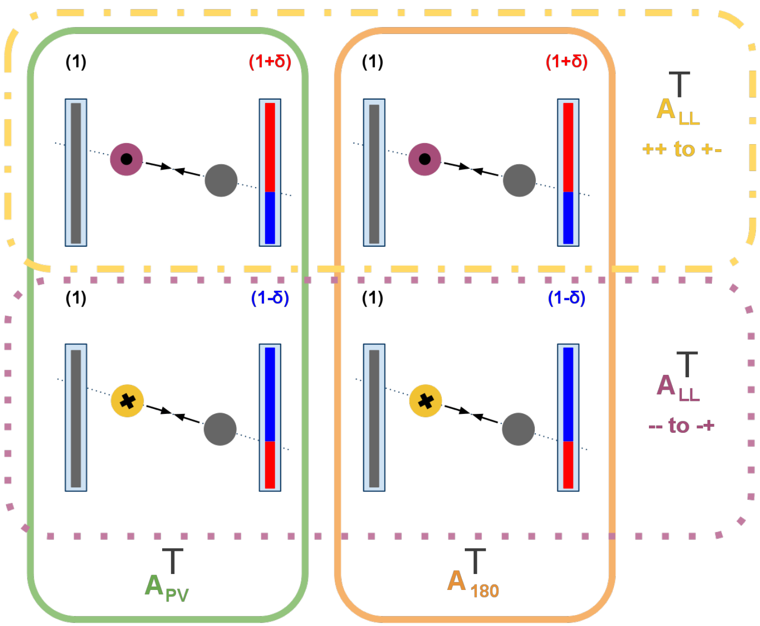
$$A^T_{PV} = \frac{(1+\delta)^2 - (1-\delta)^2}{(1+\delta)^2 + (1-\delta)^2} \approx 2\delta$$

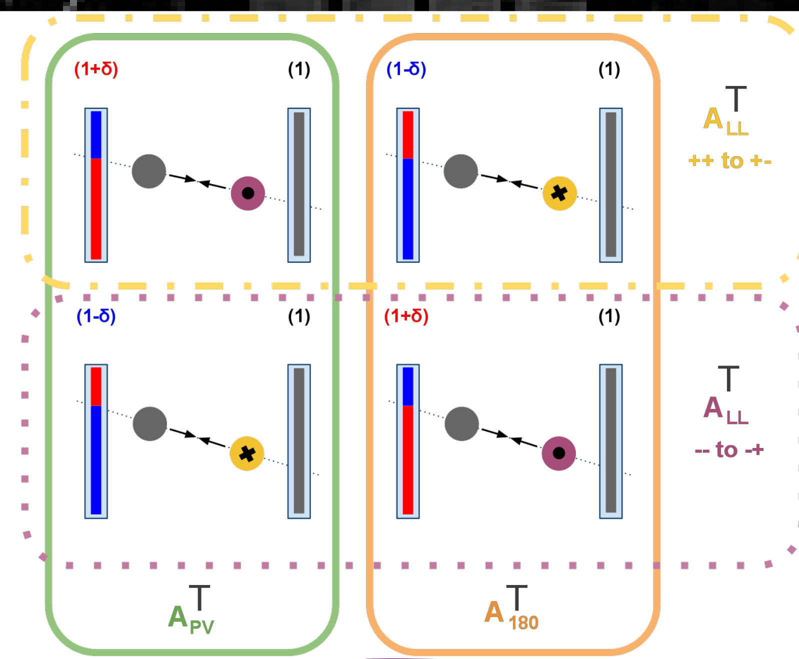
$$r = \frac{(\epsilon_N \epsilon_S \lambda)_{ZDC}}{(\epsilon_N \epsilon_S \lambda)_{BBC}}$$

$$\approx a(1 \pm \delta) a(1 \pm \delta) \left(\frac{(\epsilon_N \epsilon_S \lambda)_{ZDC}}{(\epsilon_N \epsilon_S \lambda)_{BBC}} \right)_{nominal}$$

Single spin contributions

- e.g.: parity violating asymmetry A_{PV} (++ vs. --) with collinear beam angles
- Same assumptions





$$A^T_{PV} = \frac{(1+\delta)-(1-\delta)}{(1+\delta)+(1-\delta)} = \delta$$

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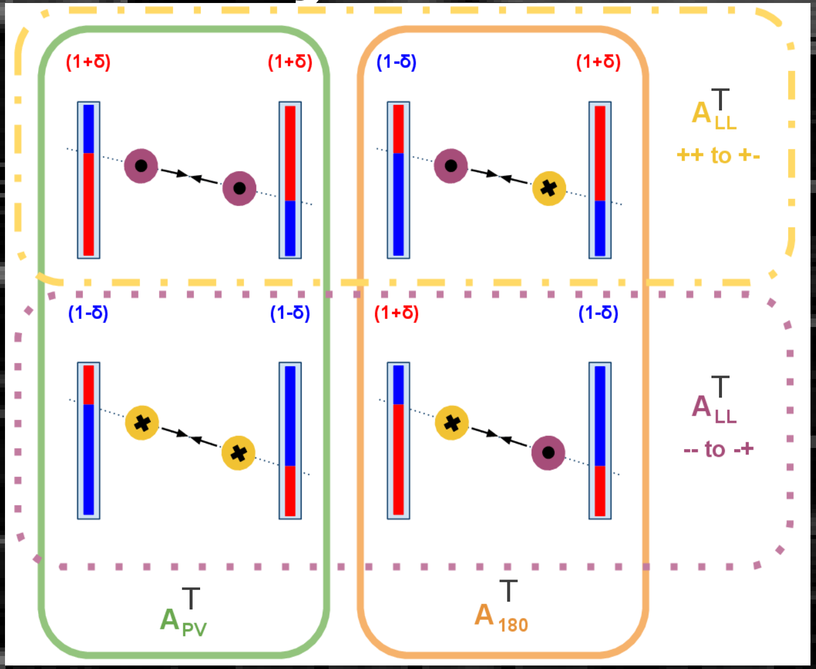
Polarization Weighted Summing

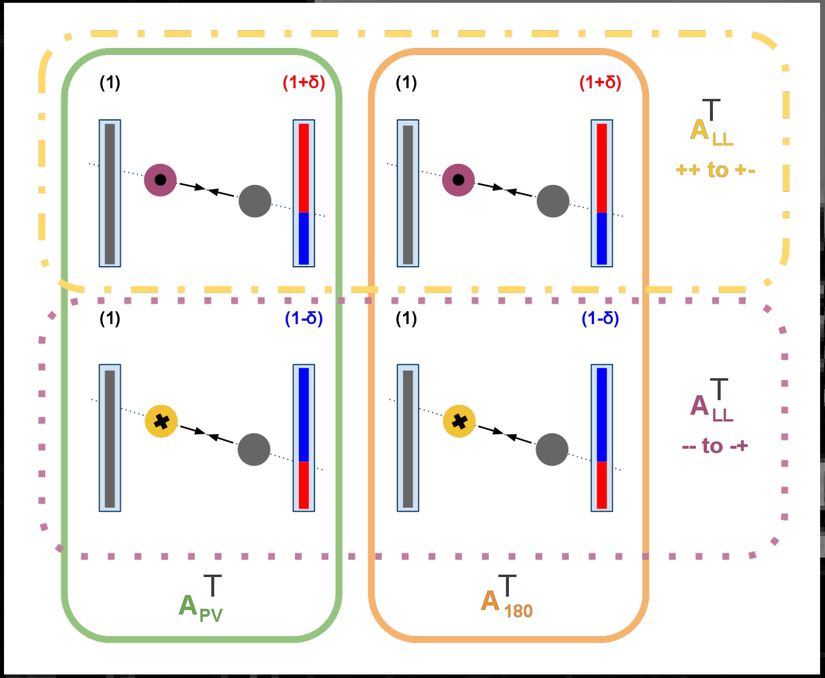
$$A^{T}_{PV} = P_1(1-P_2)\delta + (1-P_1)P_2\delta + P_1P_2\delta$$
$$= (P_1+P_2)\delta$$

- This is a single-spin effect (scales as polarization^1)
  - Masquerading as a double-spin asymmetry

Generating Double Spin Asymmetries

- Similarly, we can generate some A^T_{LL}s, such as
  - A^T_{LL} (++ to +-) and
  - A^T_{LL} (-- to -+)
- Technically, these have A^T_Ls in them, too





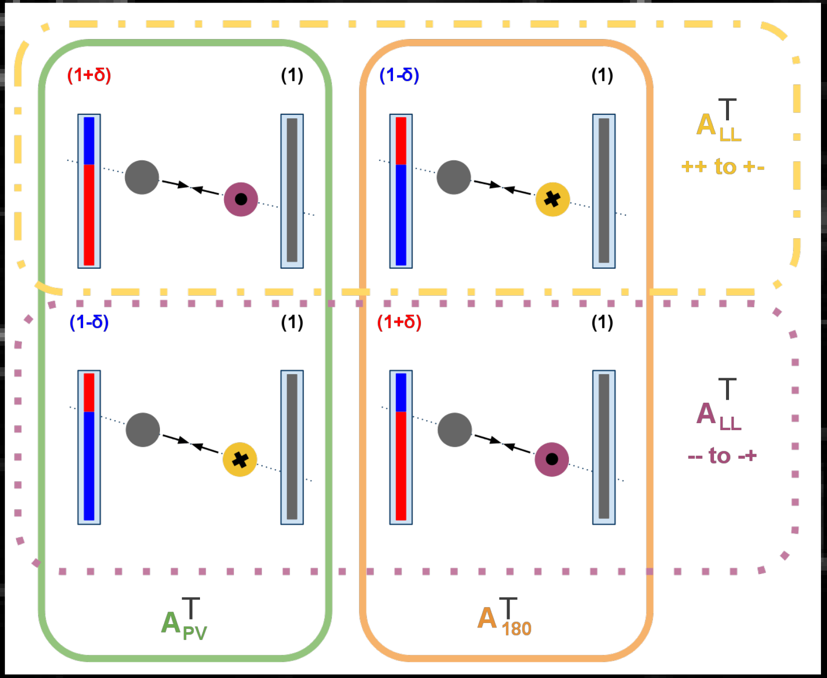


Table of “Results” from Model with equal blue, yellow pol

Situation	A^T_{PV}	A^T_{180}	A^T_{LL}(++ to +-)	A^T_{LL}(-- to -+)
collinear angles	+2Pδ	0	+Pδ	-Pδ
Offset/Boost	0	-2Pδ	+Pδ	-Pδ

- Of course, equal transverse components in the two beams isn't always the case
  - Our model still holds, but not this simplified table

Simulation (1/3)

TOY MC ingredients:

- Bunch Collisions:
  - Realistic modeling of beam collisions at 200 GeV
    - With any angles and offsets
  - Simple Gaussian shape for beams
    - With realistic size
  - Results in a 3D collision distribution

Simulation (2/3)

Particle Production:

- Simple production of particles at each collision point (quantum number, energy conservation not required)
- According to measured kinematic distributions
- Charged tracks into BBC
  - No A_N as none measured in PHENIX BBC
- Neutrons into ZDC
  - Include a p_T dependent A_N

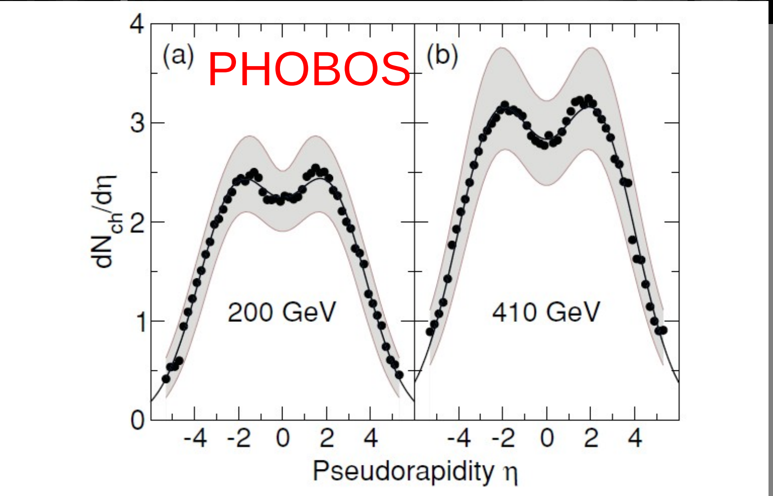
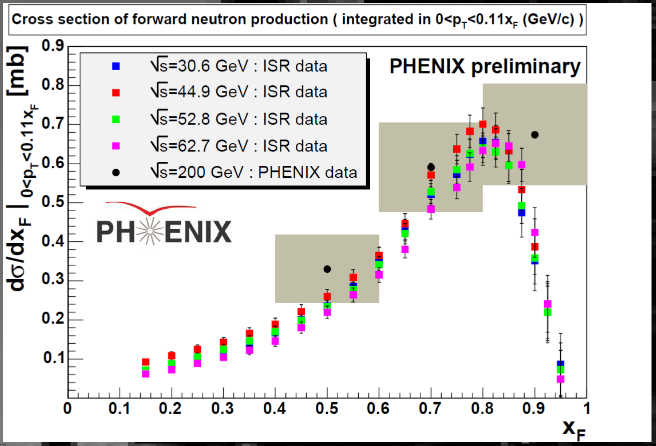
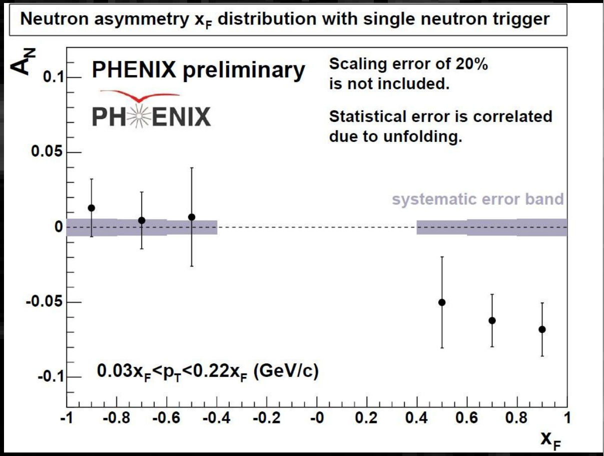


FIG. 29. (Color online) Charged-particle multiplicity $dN_{ch}/d\eta$ shown for 200-GeV (a) and 410-GeV (b) pp inelastic collisions.





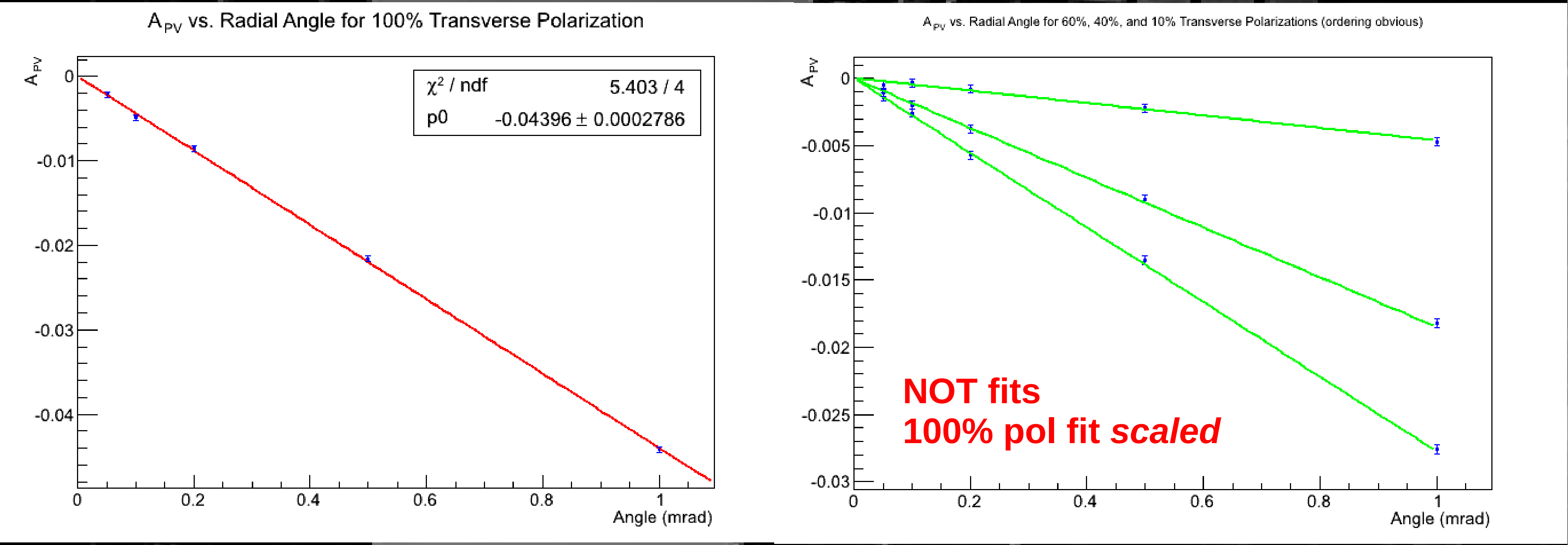
Simulation (3/3)

Detectors (geometry only)

- Realistic geometrical acceptance of BBC and ZDC
  - BBC an annulus
  - ZDC a rectangle (projection of true shape onto x-y plane)
  - Both have some extent in z

(latest) Simulation Results (p_T dependent A_N)

- Linear dependence $2\delta(\theta) = -0.044*\theta$ (in mrad)

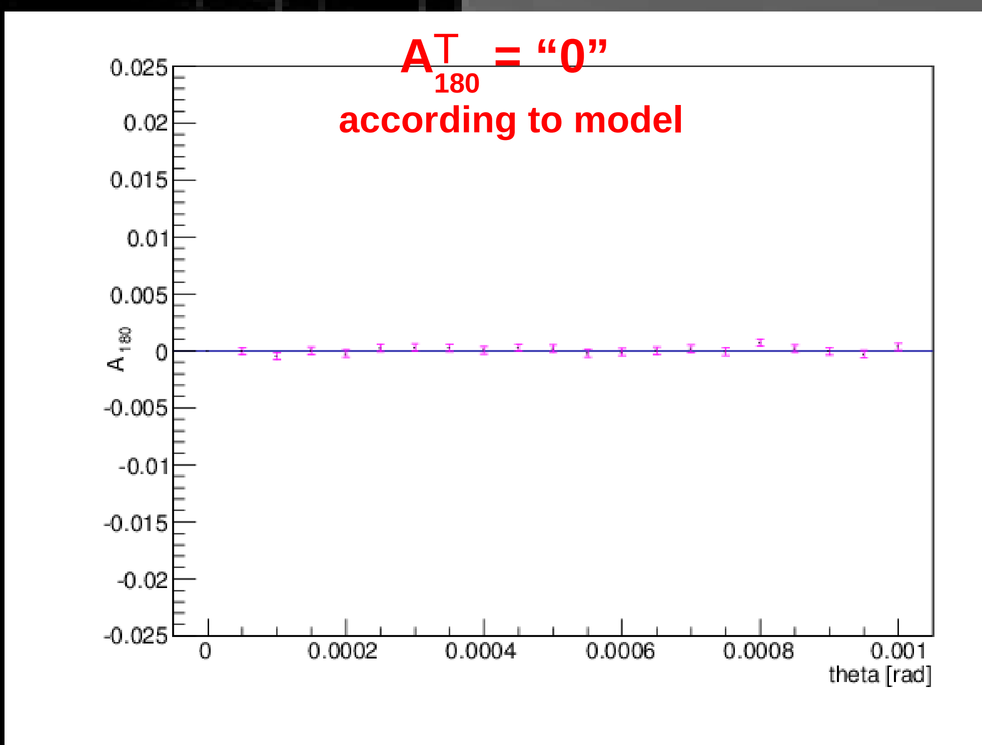


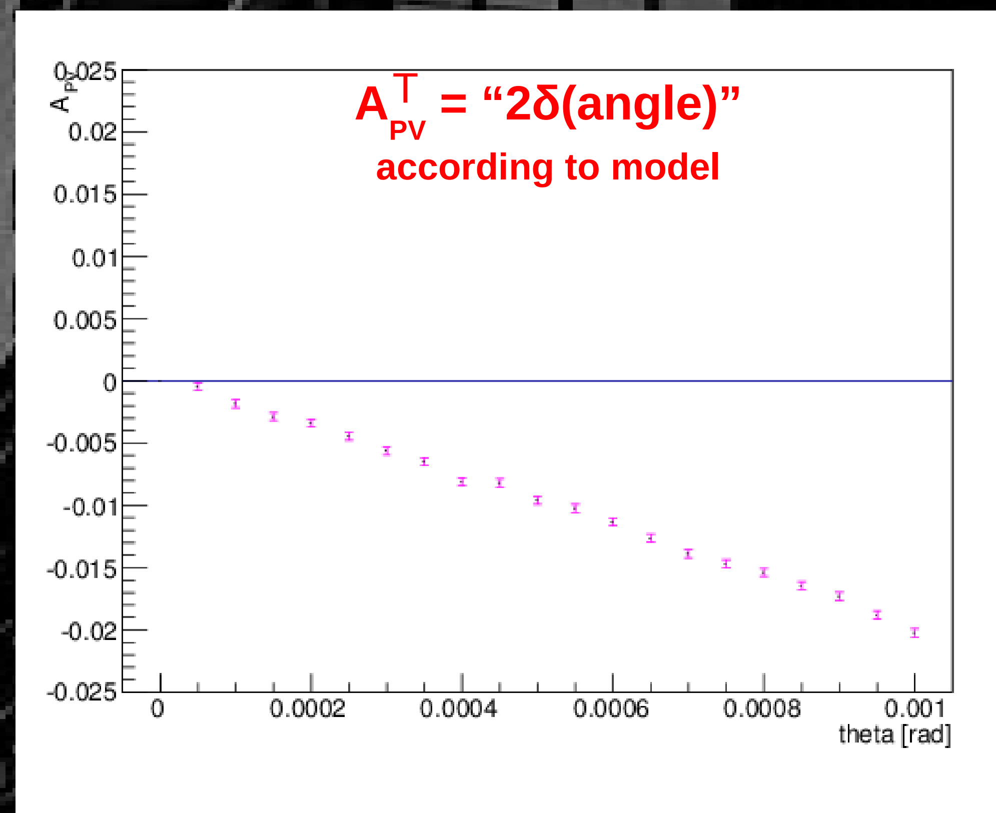
- **Transverse** polarization Scaling Confirmed

(not quite latest) Simulation Results (does not include p_T dependent A_N)

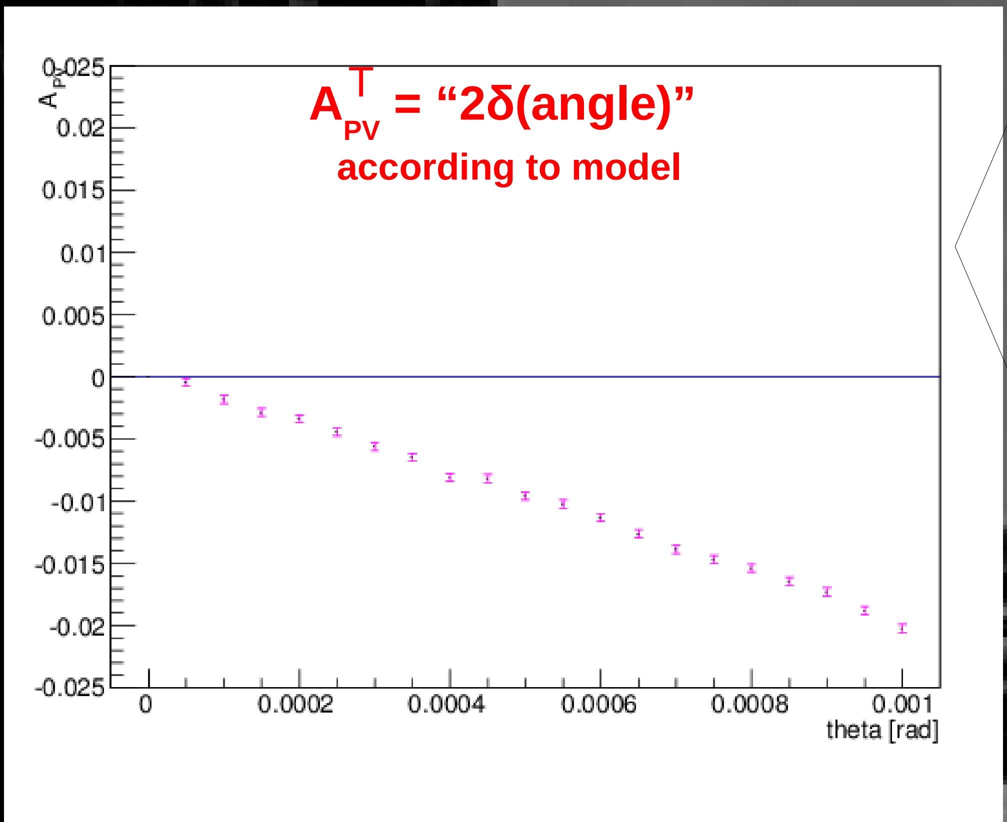
- Pure **Angle**
- What is plotted?
  - Asymmetries vs. angle in plane $\perp$ to (vertical) polarization

+angle defined oppositely from model

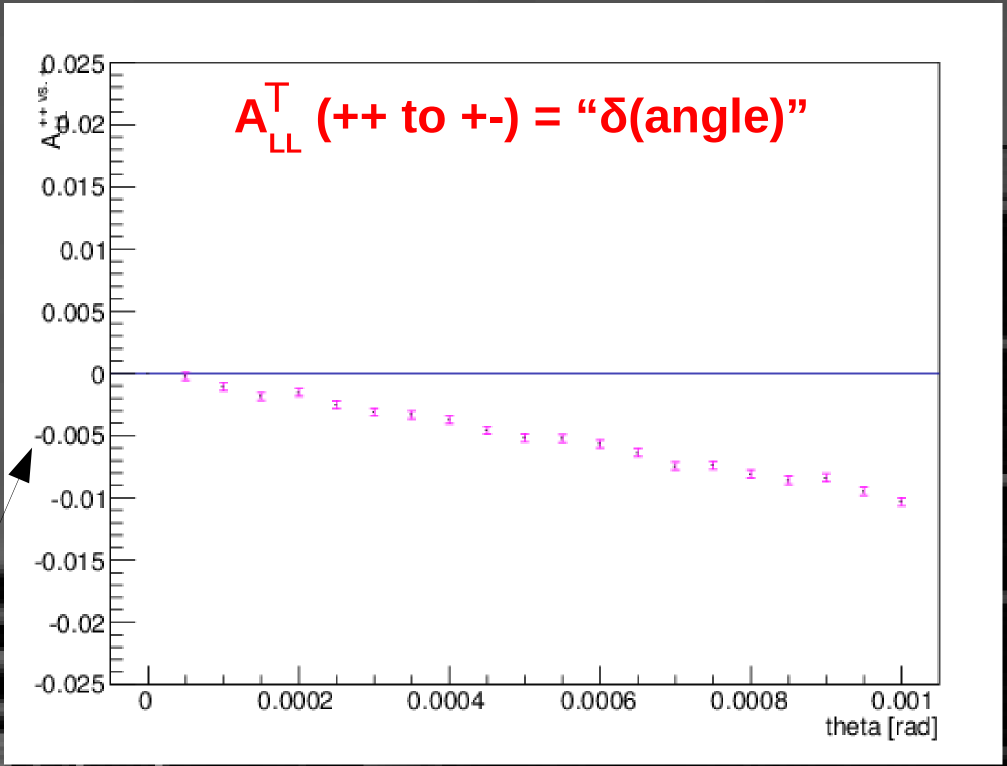




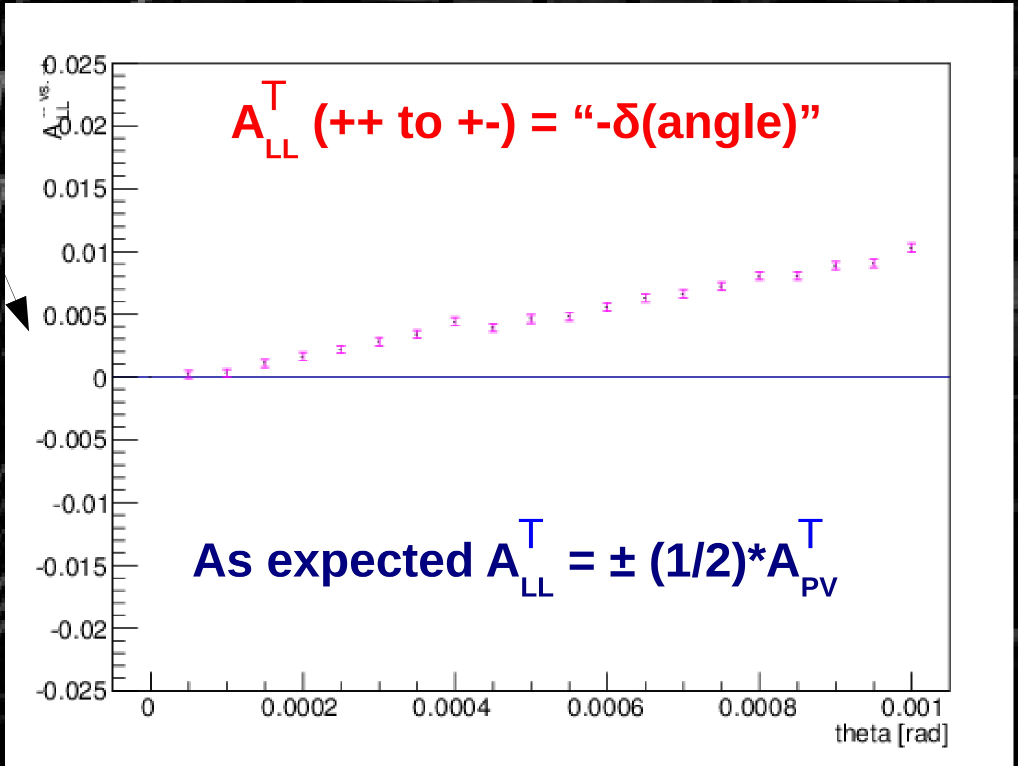
A^{T}_{LL}



A^{T}_{PV} = "2δ(angle)"
according to model
A_{PV}
theta [rad]



A^{T}_{LL} (++ to +-) = "δ(angle)"
theta [rad]



A^{T}_{LL} (++ to +-) = "-δ(angle)"
As expected $A^{T}_{LL} = \pm (1/2)*A^{T}_{PV}$
theta [rad]

Actual **LONGITUDINAL** Data

- Fitting

$$r = \frac{(\epsilon_N \epsilon_S \lambda)_{ZDC}}{(\epsilon_N \epsilon_S \lambda)_{BBC}}$$

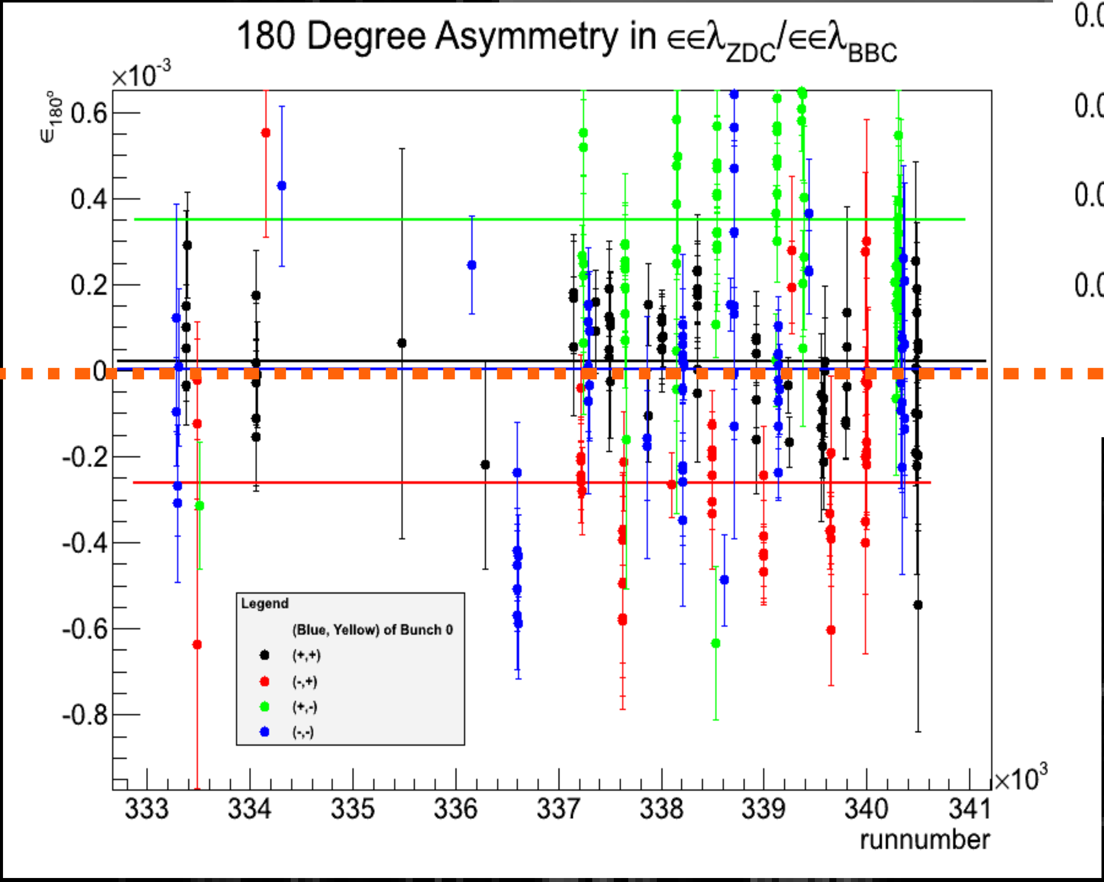
- To bunch-fitting formula

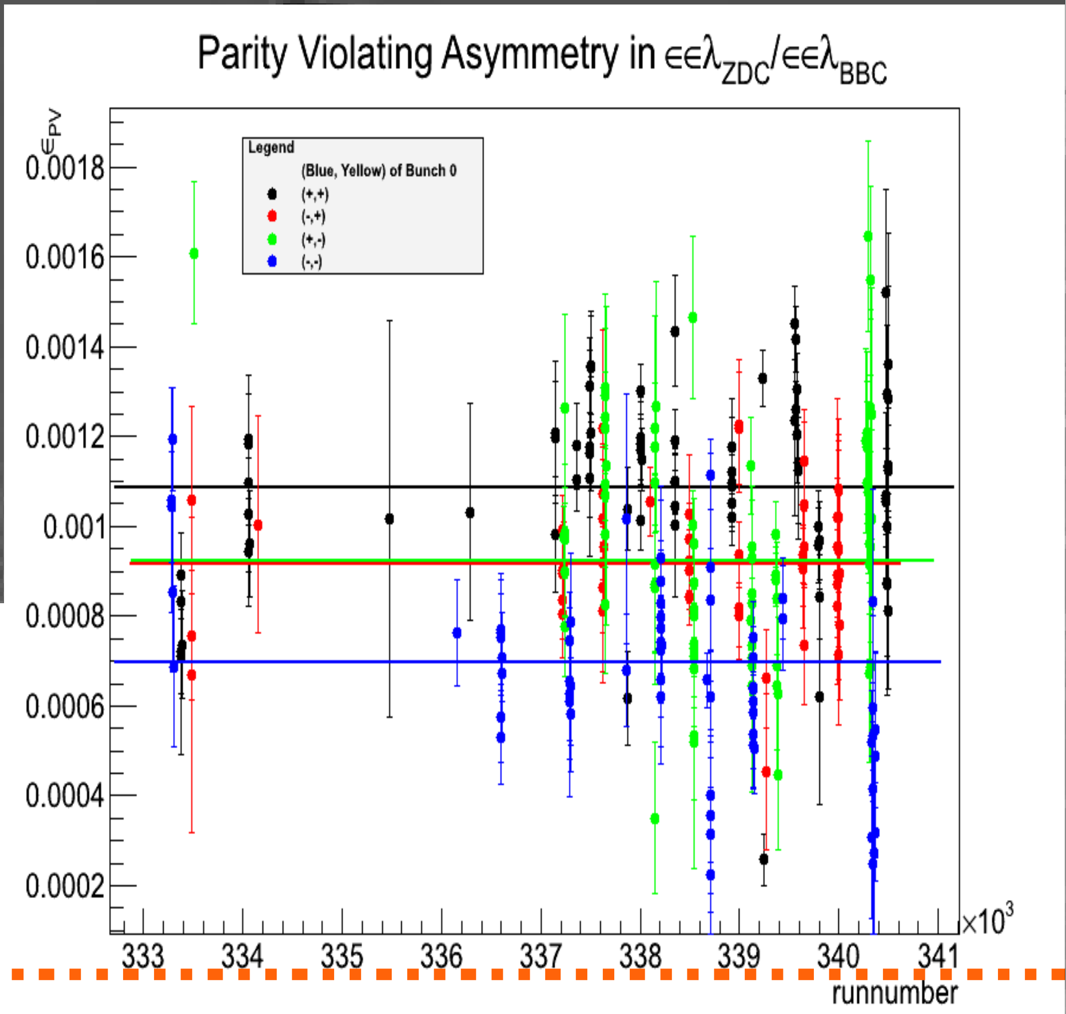
$$r_i = c(1 + S_b S_y \epsilon_{LL})$$

- Separated by the overall spin vs. xing pattern
  - **4 used in RHIC**, different every fill
  - Bunch structure causes some separation in these
  - Averaging patterns would wash out the effect somewhat

Run11 500 GeV **Longitudinal:** A_{180}, A_{PV}

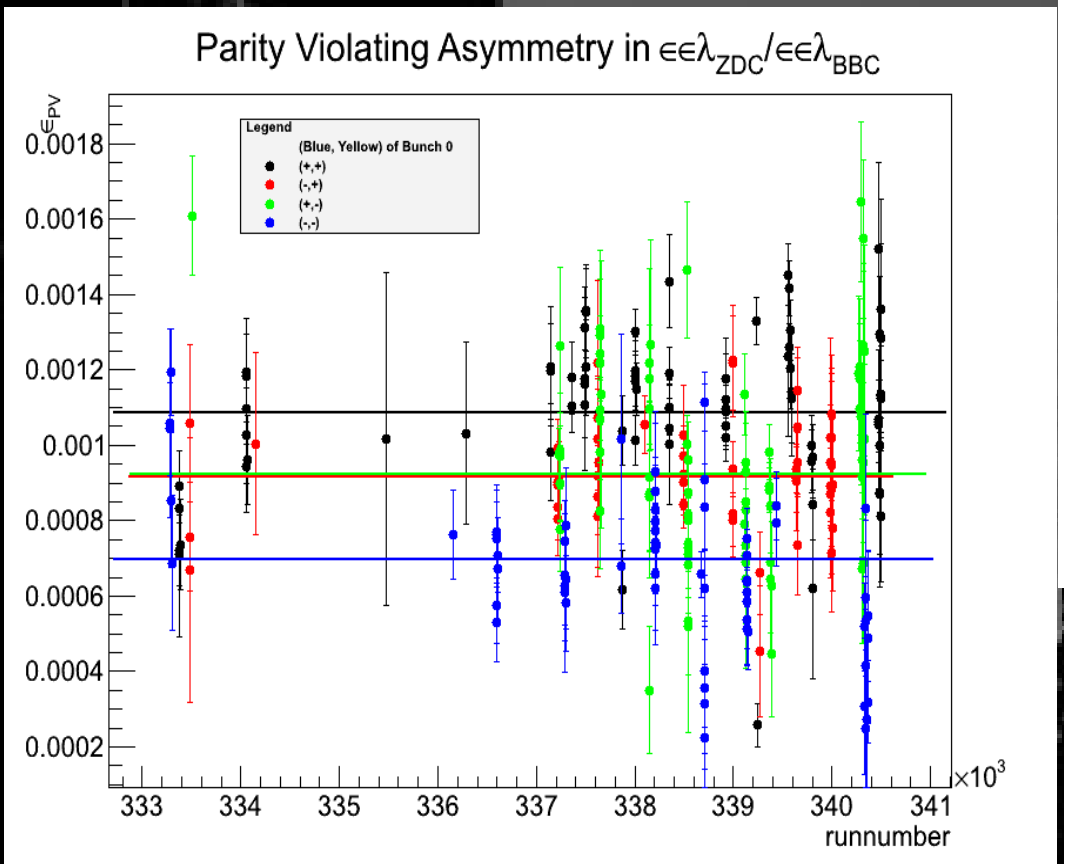
Tempted to Conclude:
Co-linear angles, not offsets/boosts in Run11

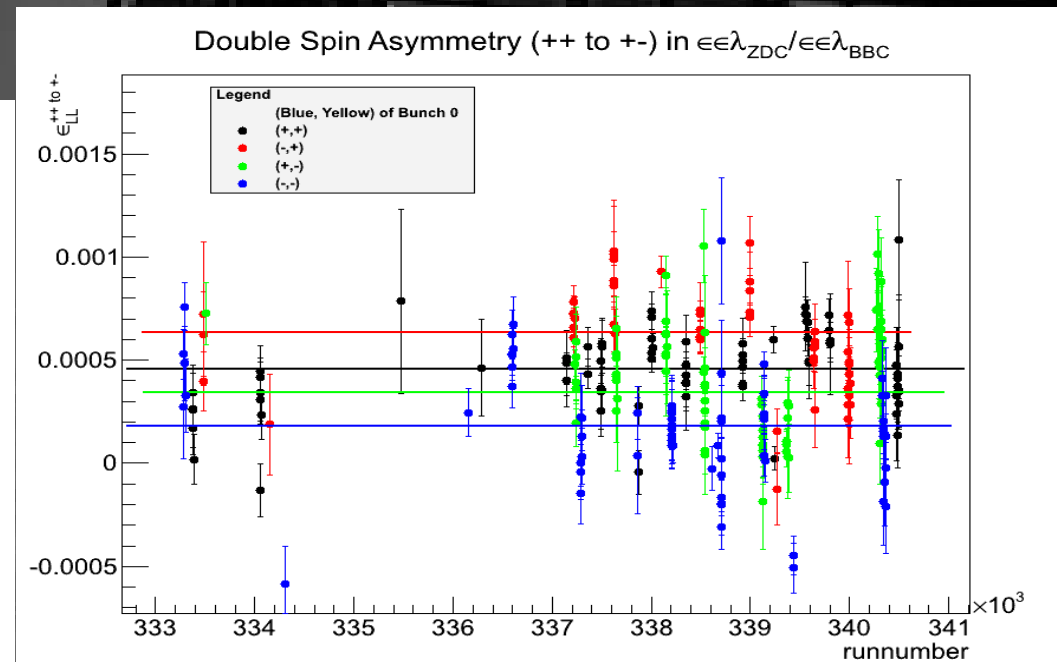


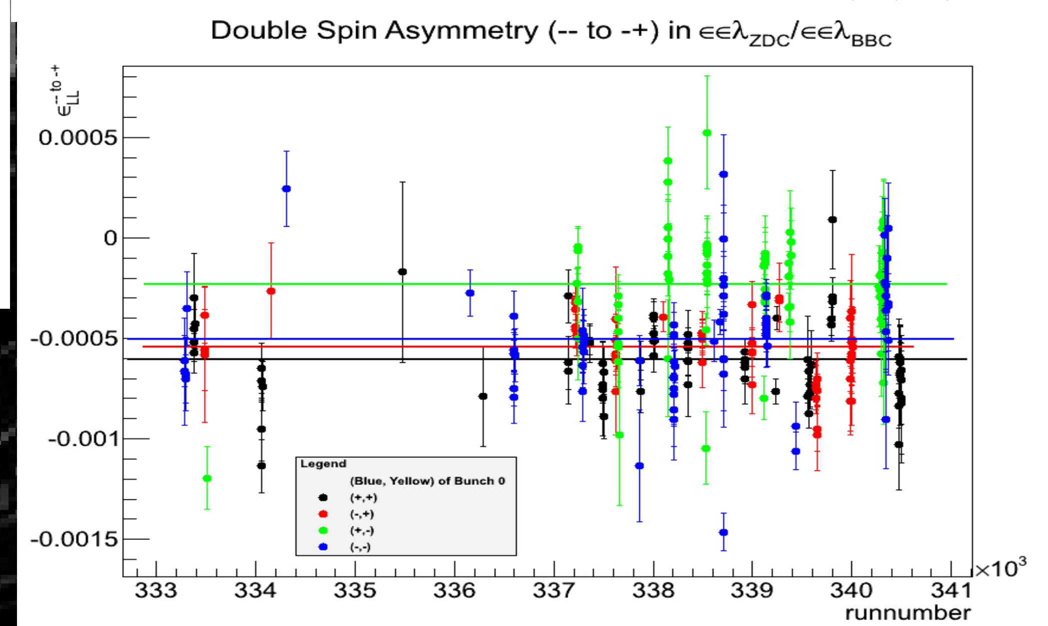


SHOWN ON SAME SCALE
i.e. common axis for the entire SLIDE

Run11: A_{PV}, A_{LL}(++ to +-), A_{LL} (-- to -+)







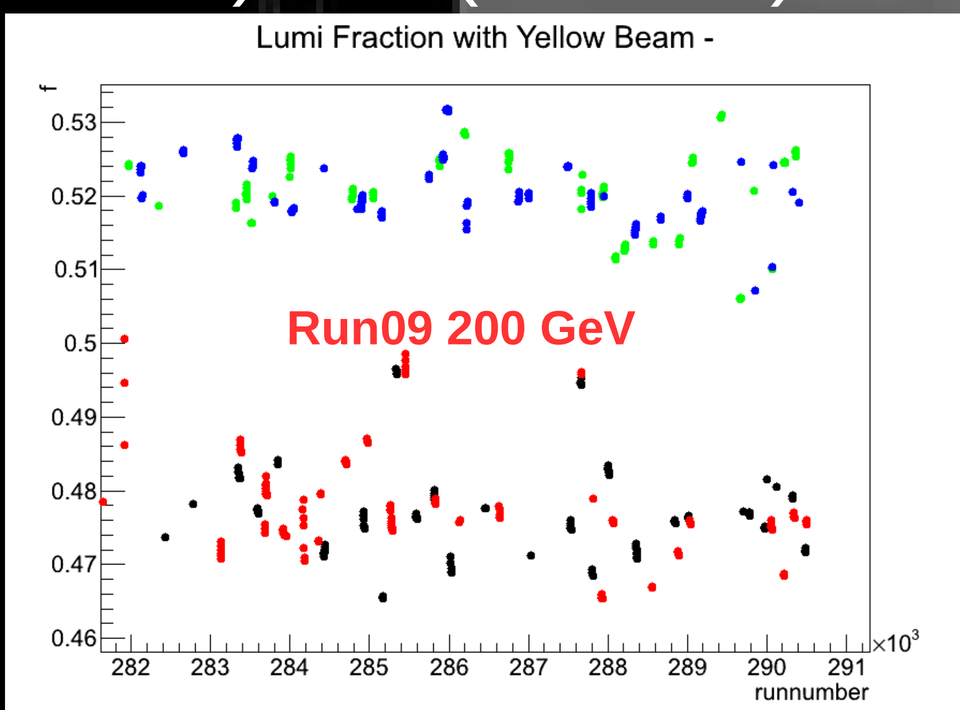
Remember, according to simple model

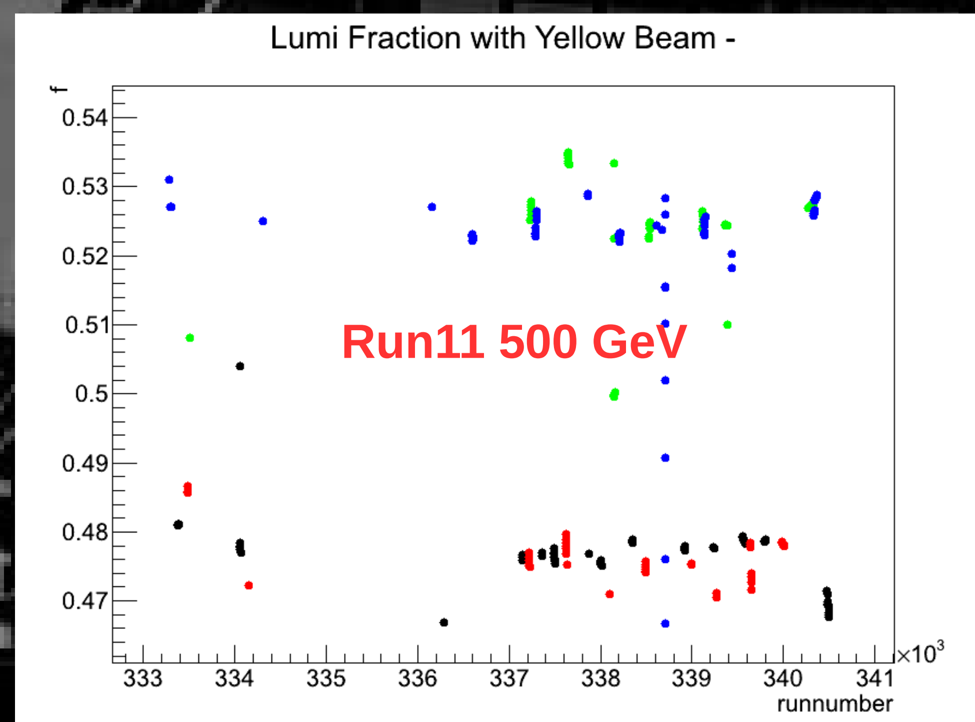
A_{LL}(++ to +-) = 0.5 A_{PV}

A_{LL}(-- to -+) = -0.5 A_{PV}

What About Our Traditional A_{LL} ?

- Our traditional takes (++,--) vs. (+-,-+)
- So essentially, we are taking a luminosity weighted average of the other two A_{LL}s (++ vs. +-) and (-- vs. -+)





- Run12 Beam Study
  - p+p 200 GeV transverse
  - beam angles

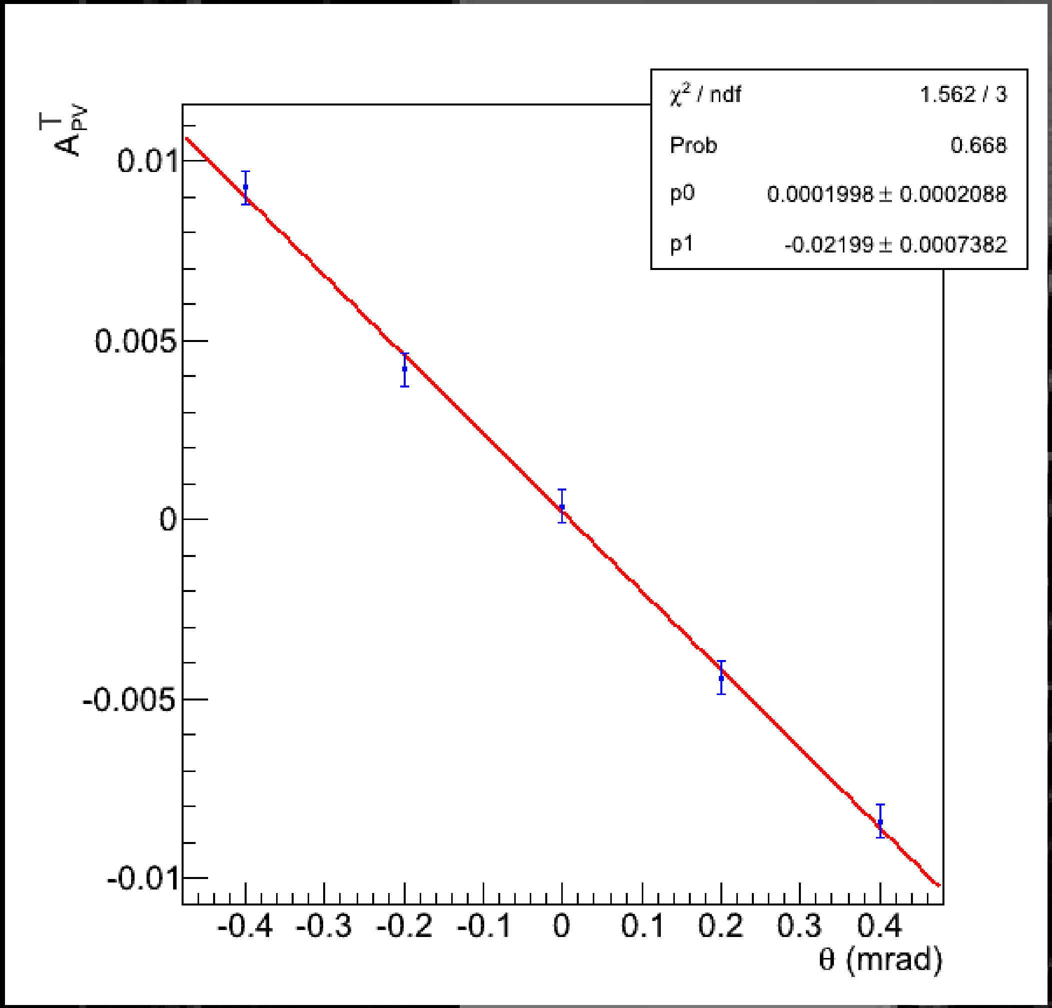
Study Outline

- Run transversely polarized beams w/ angles
  - In 200 GeV p+p to start
- Analysis uses scaler counts
- Do not want to interfere with local-pol measurements
- Want to minimize impact to physics programs
  - Beam angling likely to increase BGs in places

Study: Possibilities (CAD)

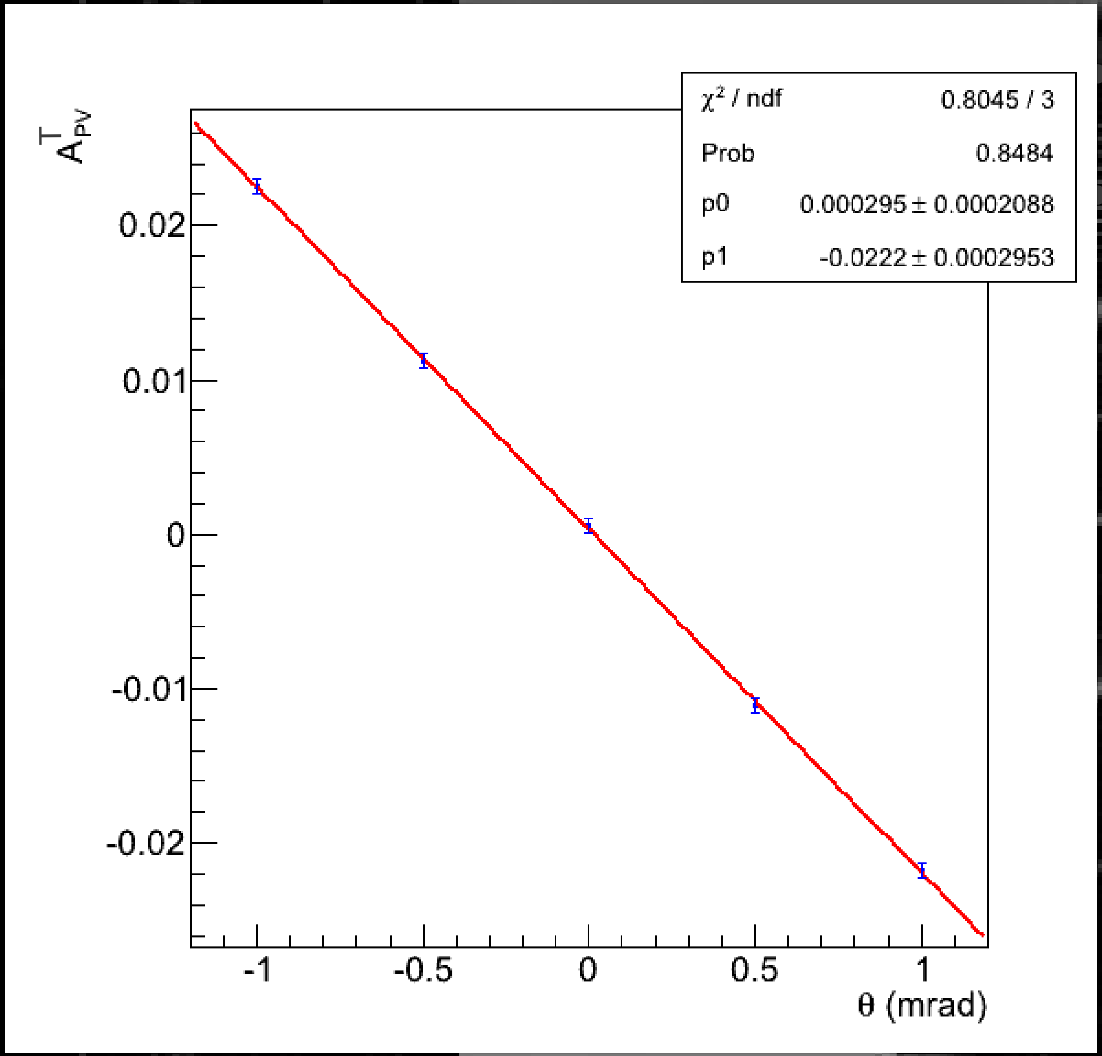
- Know we can get ~400 μrad max angle from CAD
  - Done in Run05 Vernier scan at PHENIX
  - want bigger angles if possible
- Do (-400 μrad, -200 μrad, 0 μrad, 200 μrad, 400 μrad) = 5 fills
- Do all in the same Fill Pattern (instead of mixing 2 biases among 5 measurements)
- 8 hr long Fills requested
  - If Fill lost early, we would like to take a mulligan
- We would NOT like to do this immediately at the start of the Run12
  - want to look at data in nominal setting first

Uncertainty Prediction, 400 μrad



- 50% pol assumed
- With 5, 8hr fills, we could get uncertainty on slope of ~3%
- Can calibrate θ=zero to δ(intercept)/slope **= 10 μrad**
- Could add beam *offsets* if given 4 more Fills
  - Will wait for angle results b4 requesting this

Uncertainty Prediction, 1 mrad



50% pol assumed

With 5, 8hr fills, we could get uncertainty on slope of
~1% (vs ~3%)

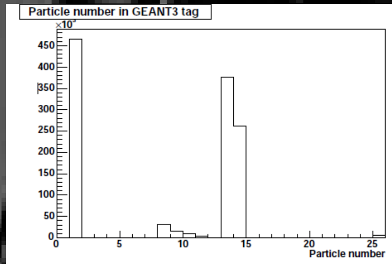
Conclusions

- Relative Luminosity systematic uncertainty is currently limiting our high statistics A_{LL} measurements
- **PHENIX wants 5 8hr Fills in Run12 200 GeV with collinear beam angles to test our hypothesis**
  - As large of angles as we can get
  - -400, -200, 0, 200, 400 μrad scan should be possible
- Depending on Outcome, may make a further request
  - Beam offsets at 200 GeV
  - Short study at 500 GeV
- With the knowledge gained from this study, we hope to reduce our RL systematic
  - Could revive the PHENIX ΔG program

- BACKUP

Input to Uncertainty Estimate (in addition to simulation)

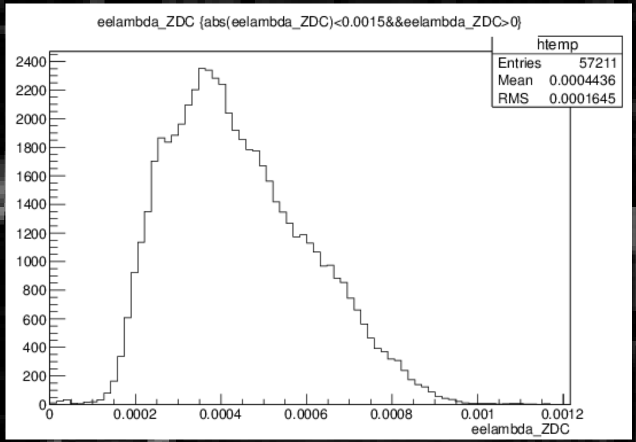
- Fraction of particles firing ZDC that are neutrons (for a conservative estimate, assume no other particles have A_N)



From: Manabu Togawa's thesis

Figure 6.21: The event structure which is detected with the ZDC in pp collision at $\sqrt{s}$=200 GeV was studied by GEANT3 with PYTHIA simulation. The ZDC threshold has set to 5 GeV in the similar to the ZDCN|S trigger. Here, I show the event that one particle is detected with the ZDC in each pp collision (about 92%). The particle tag-number in GEANT3 (summarized in Table 6.1) is plotted in the left. Major particles, the photon, neutron and proton are shown as the tag-number = 1, 13 and 14, respectively. Measured energy distributions for these three particles with the ZDC are plotted in the right figure.

- Typical ZDC rate in single crossing, $\epsilon_N \epsilon_S \lambda$



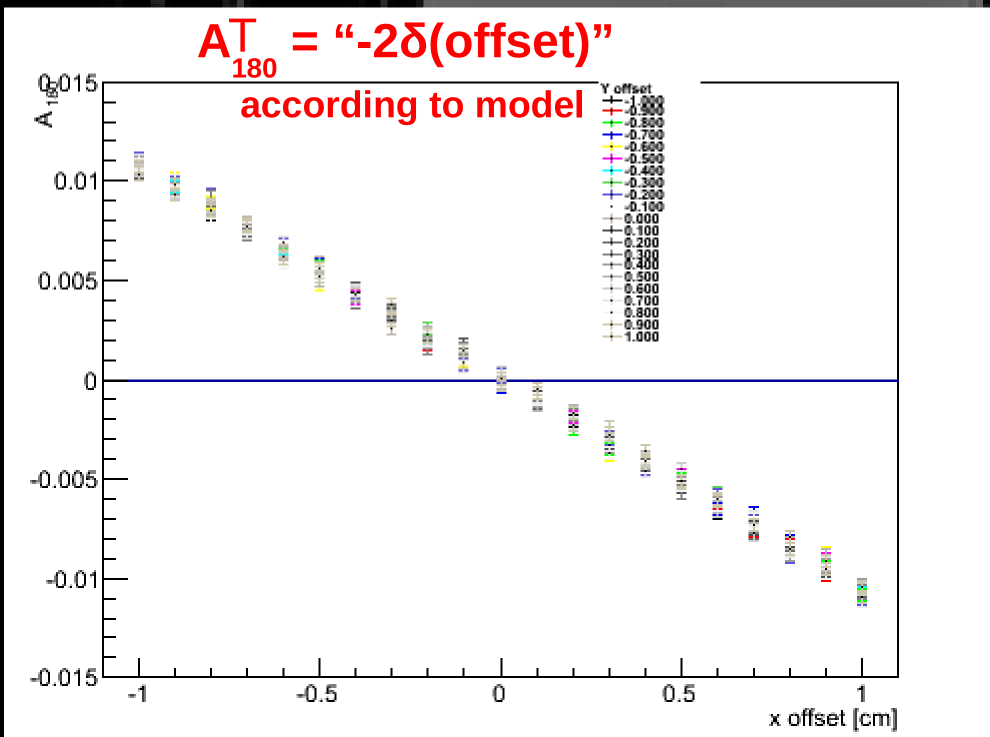
- Fractional uncertainty x:

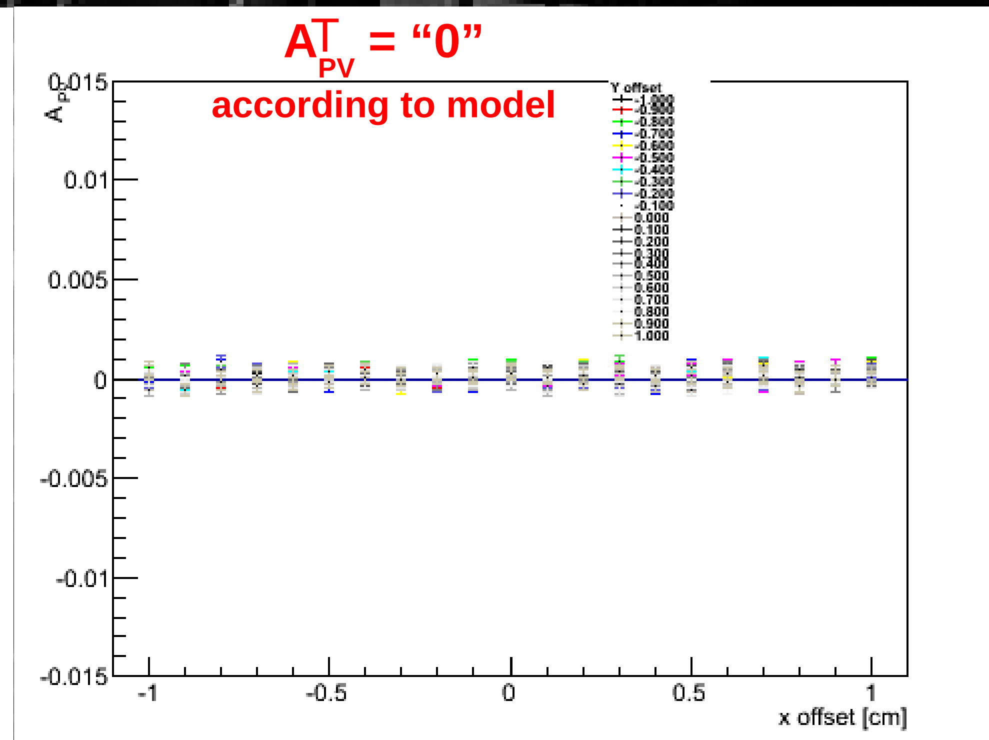
$$x\sqrt{t} \approx \frac{1}{f_{ZDC}^{neutron} m P \theta} \frac{1}{\sqrt{1.4e^{10} (\epsilon_N \epsilon_S \lambda)_{ZDC}}}$$

More Simulation Results

(not quite latest) Simulation Results (no p_T dependent A_N)

- Pure **OFFset**
- What is plotted?
  - Asymmetries vs. offset in direction ⊥ to (vertical) polarization
  - Different colors show offset in direction // to polarization (negligible effect)



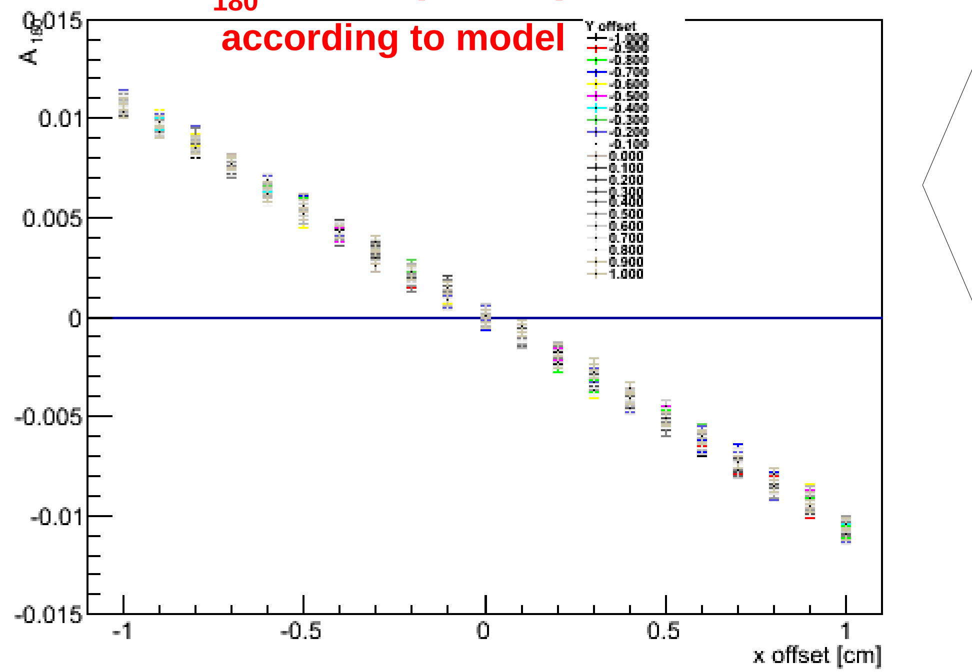


- And next the grand reveal...

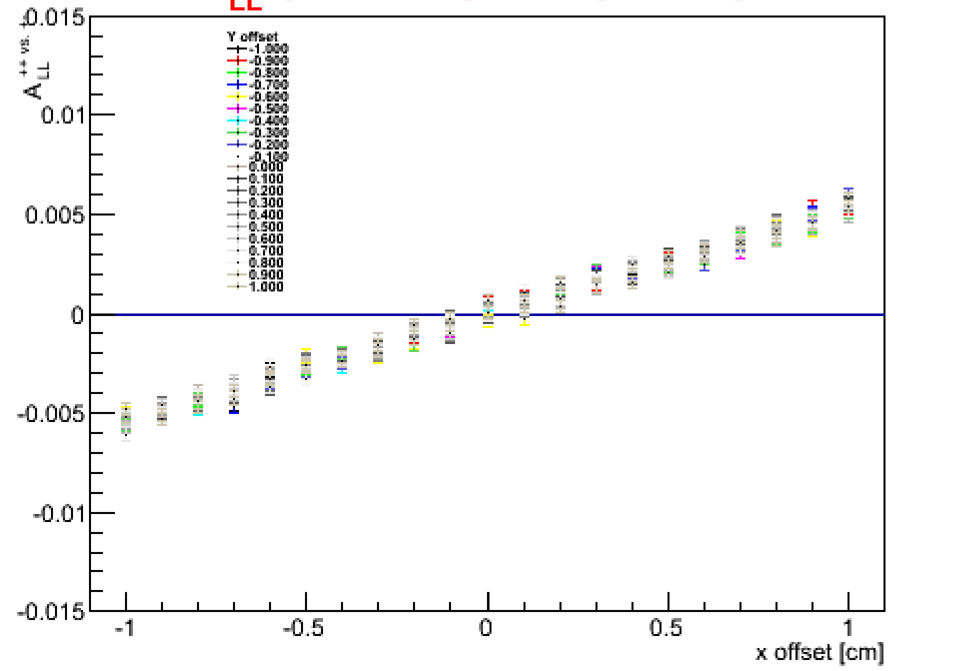
A^{T}_{LL}

A^{T}_{180} = "-2δ(offset)"

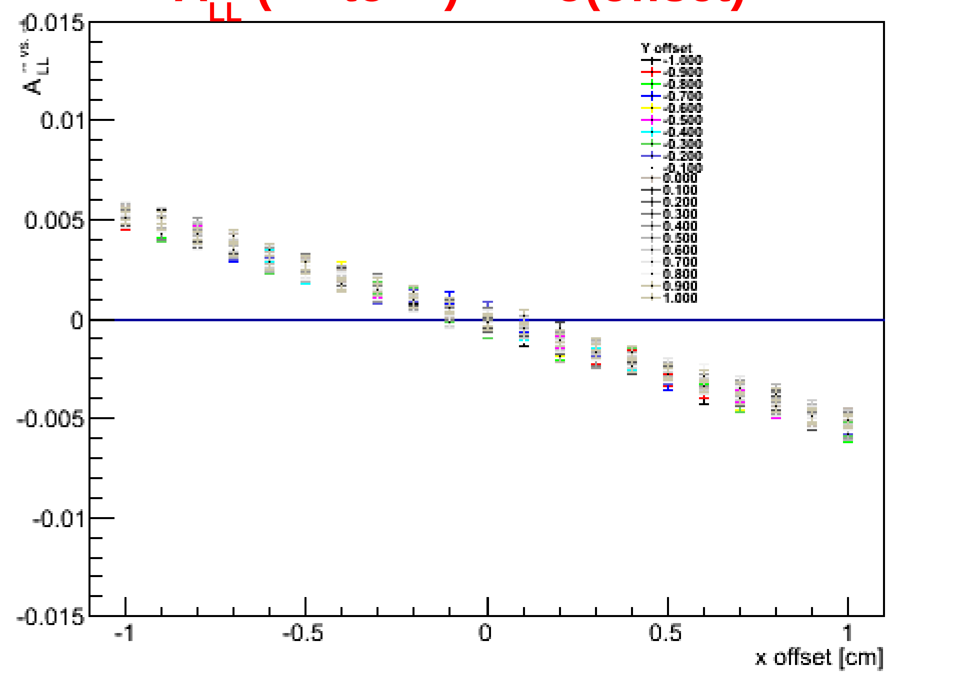
according to model



A^{T}_{LL} (++ to +-) = "δ(offset)"



A^{T}_{LL} (++ to +-) = "-δ(offset)"

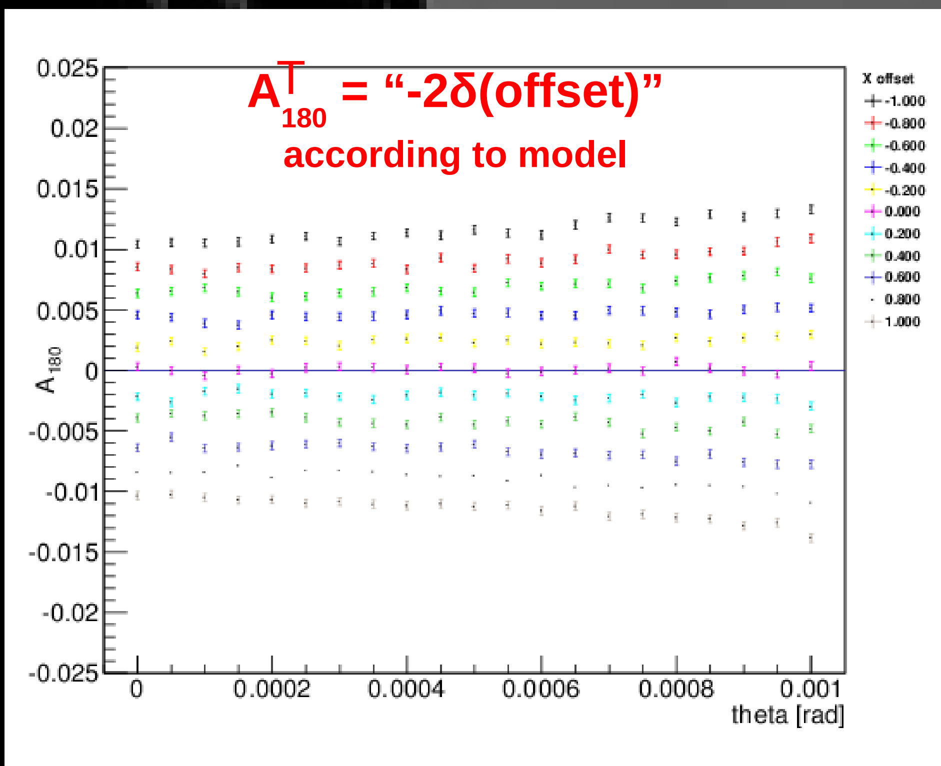


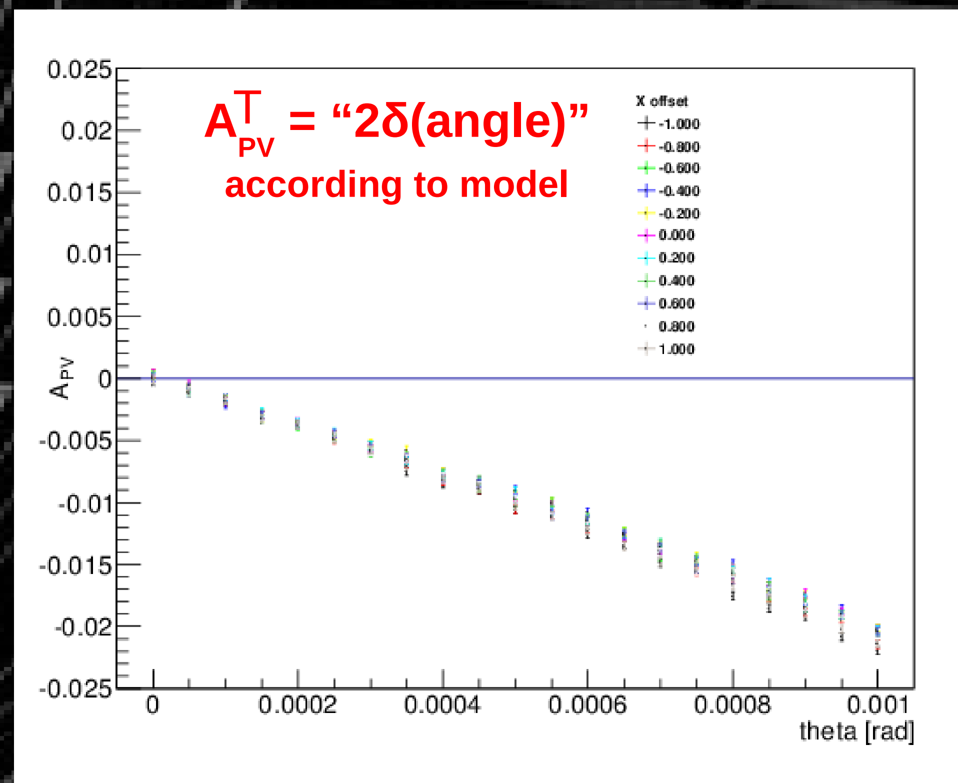
As expected A_{LL} = ± (1/2)*A_{180}

Simulation Results

- **OFFset and Angle**
- What is plotted?
  - Asymmetries vs. angle in plane ⊥ to polarization
  - Different colors show offset in direction ⊥ to polarization

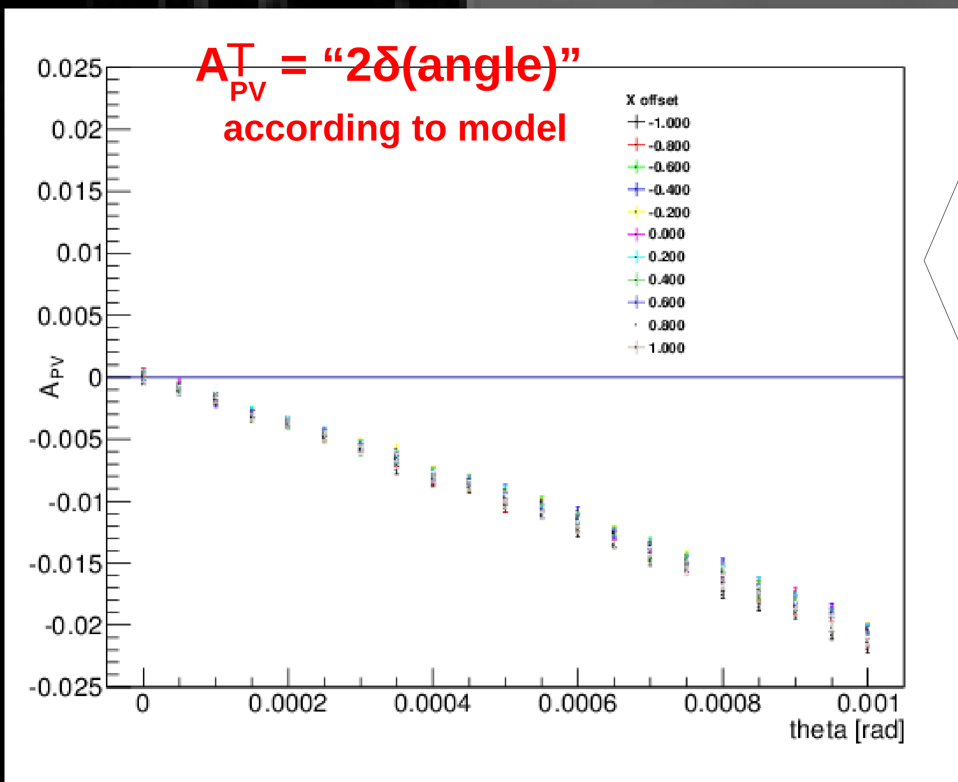
+angle defined oppositely from model

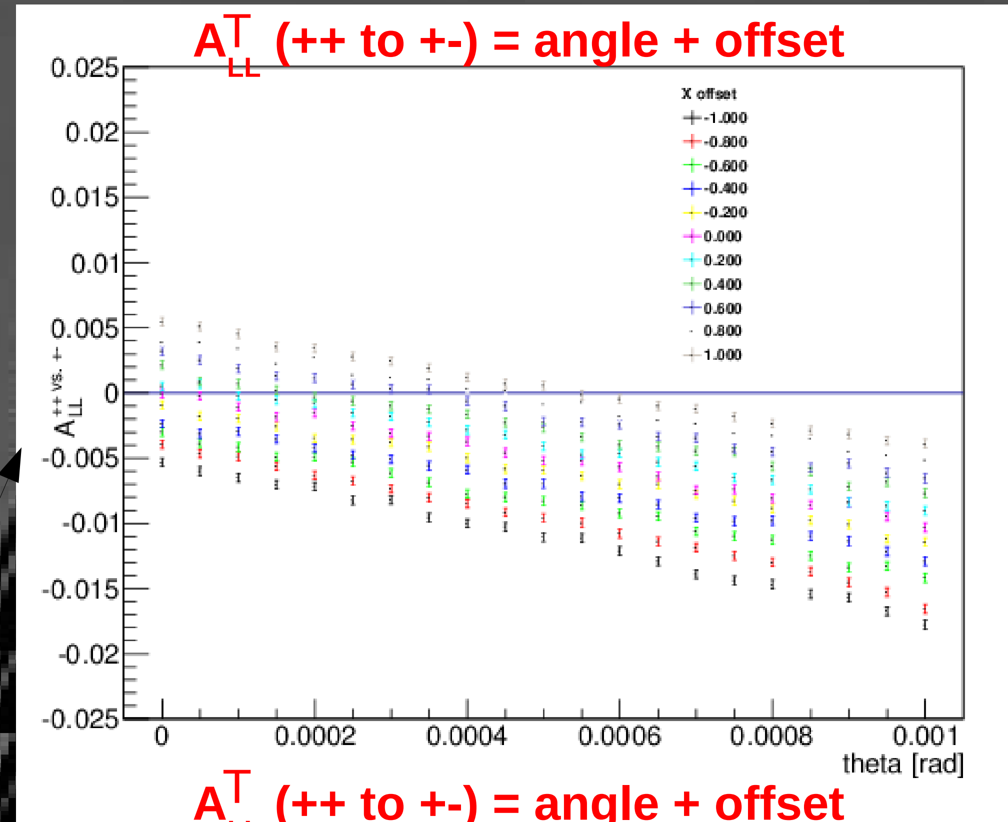


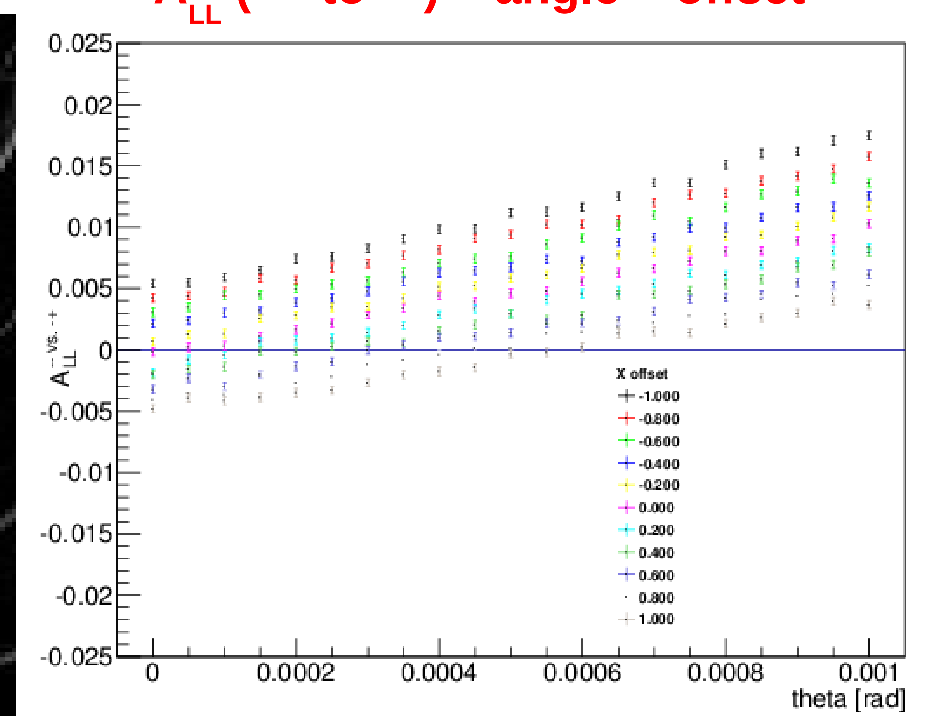


- Some small dependence of A_{180} on angle for non-zero offsets (starts going off detector)

A^T_{LL}



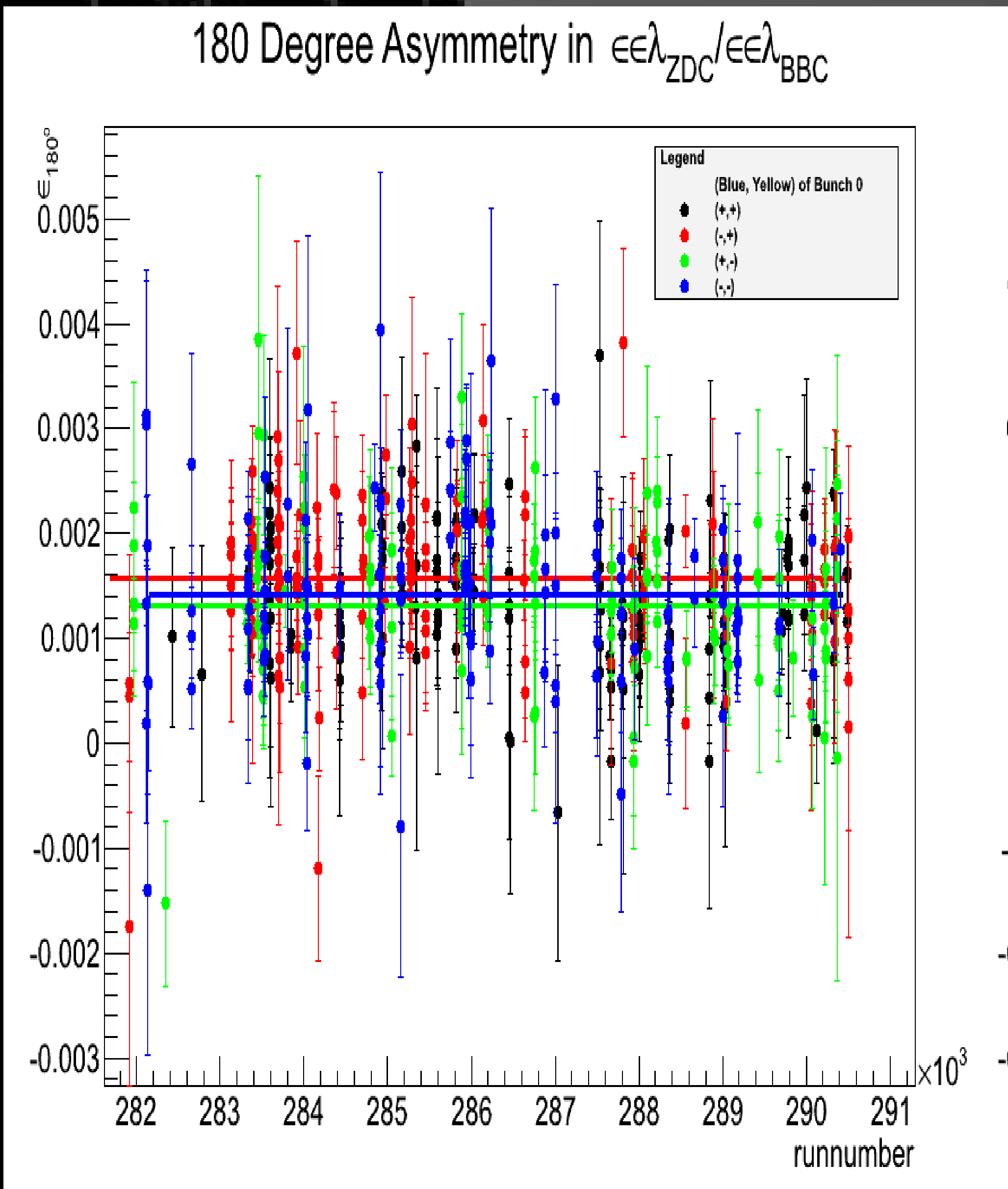




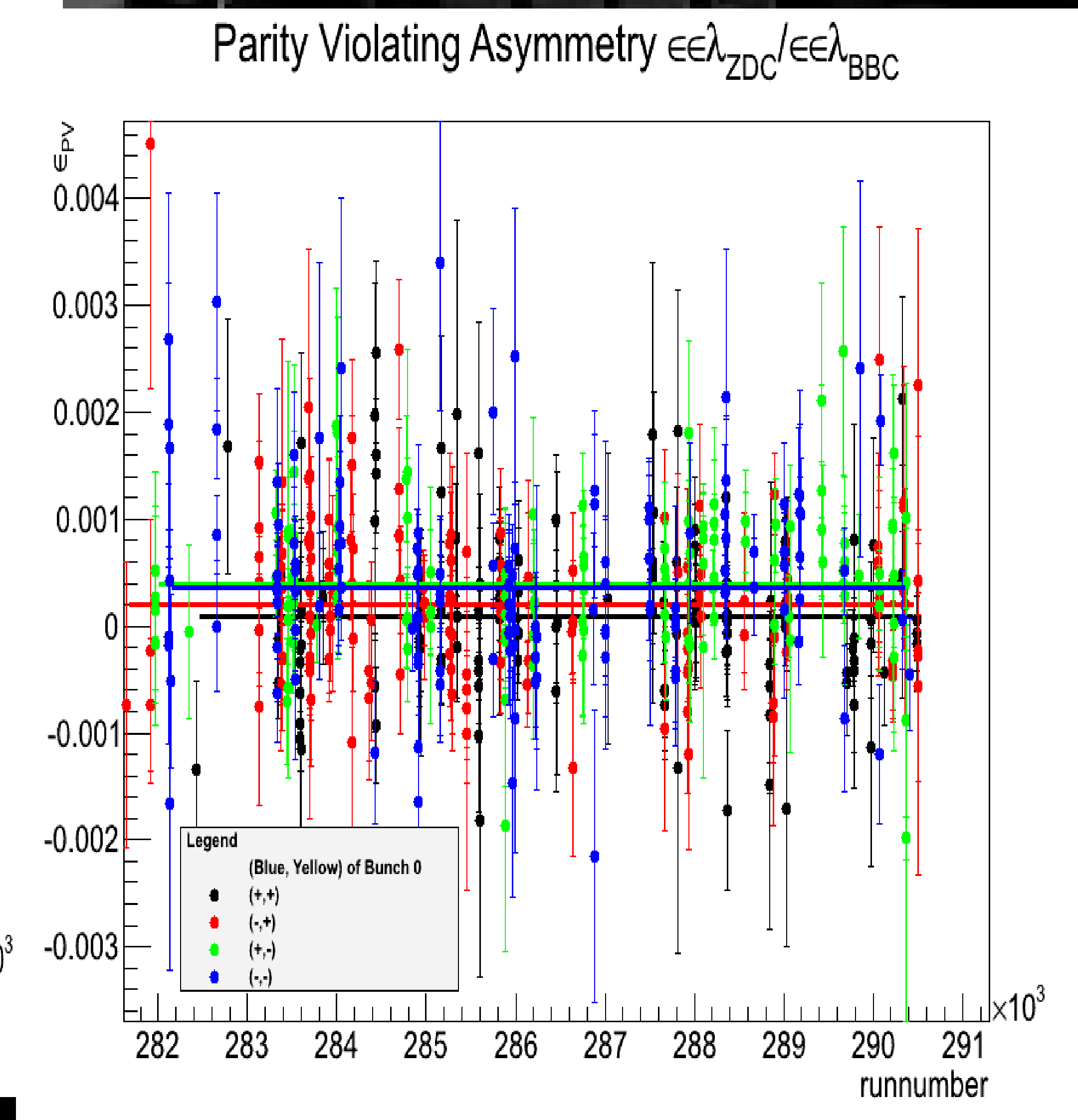
A_{LL}s are some understandable mix of angles and offsets

More Data (Run09 200 GeV Longitudinal)

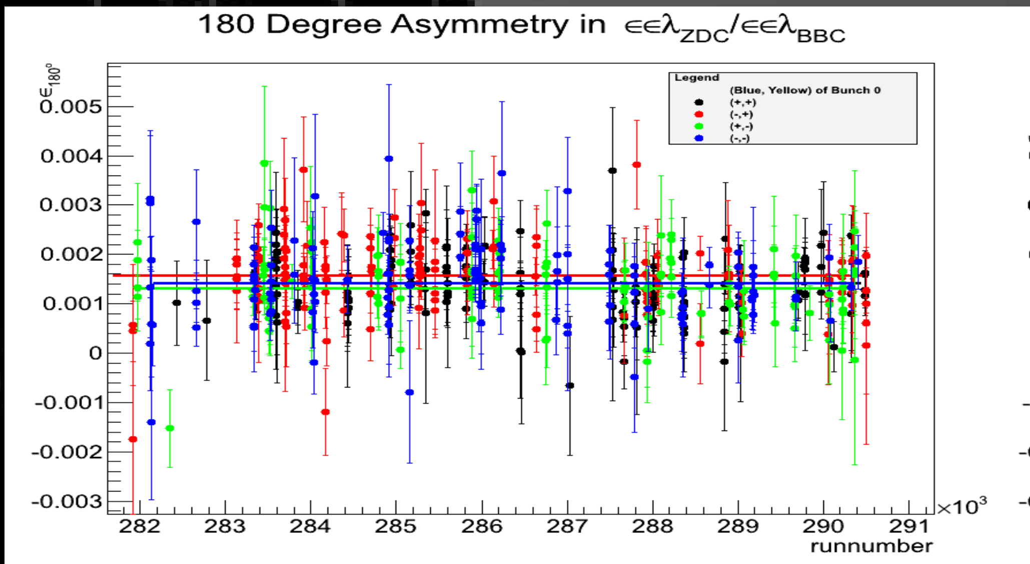
Run09: A_{180}, A_{PV}

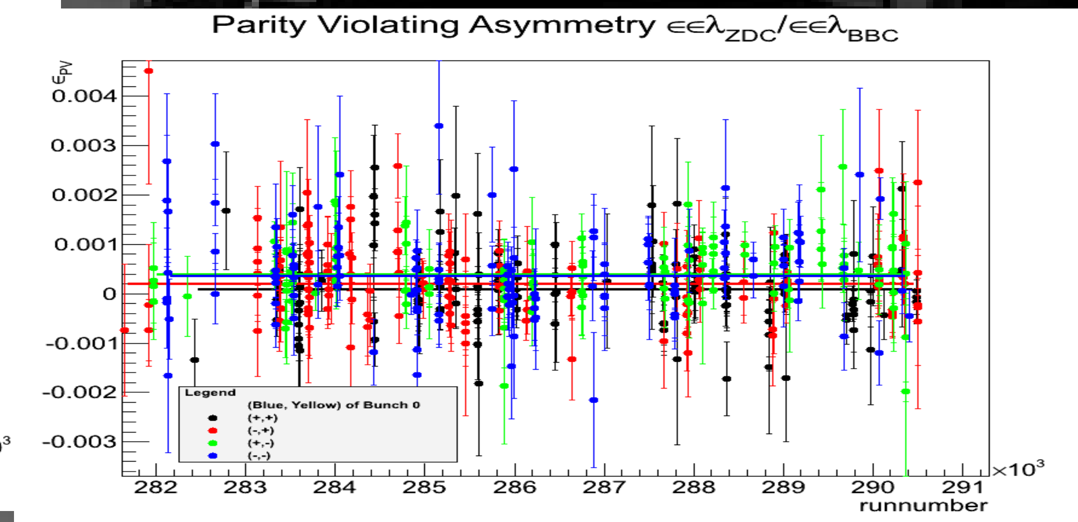


SHOWN ON SAME SCALE

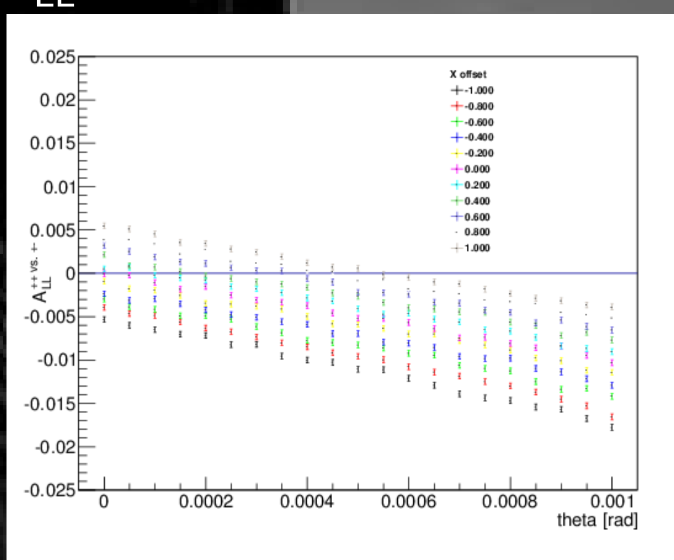


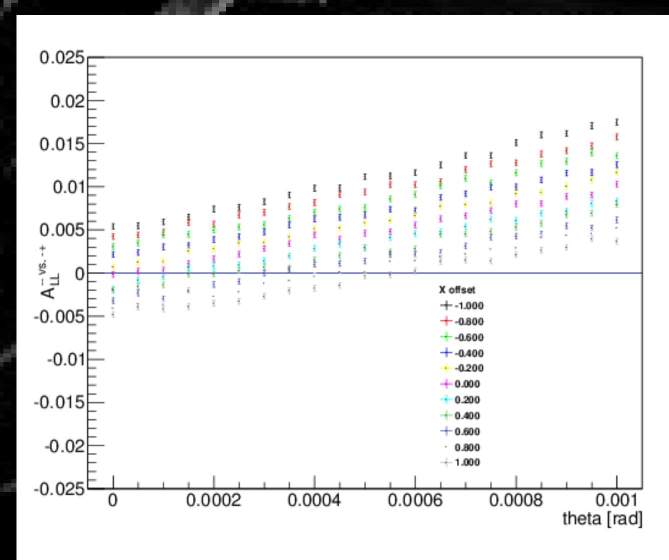
Run09: A_{180}, A_{PV}



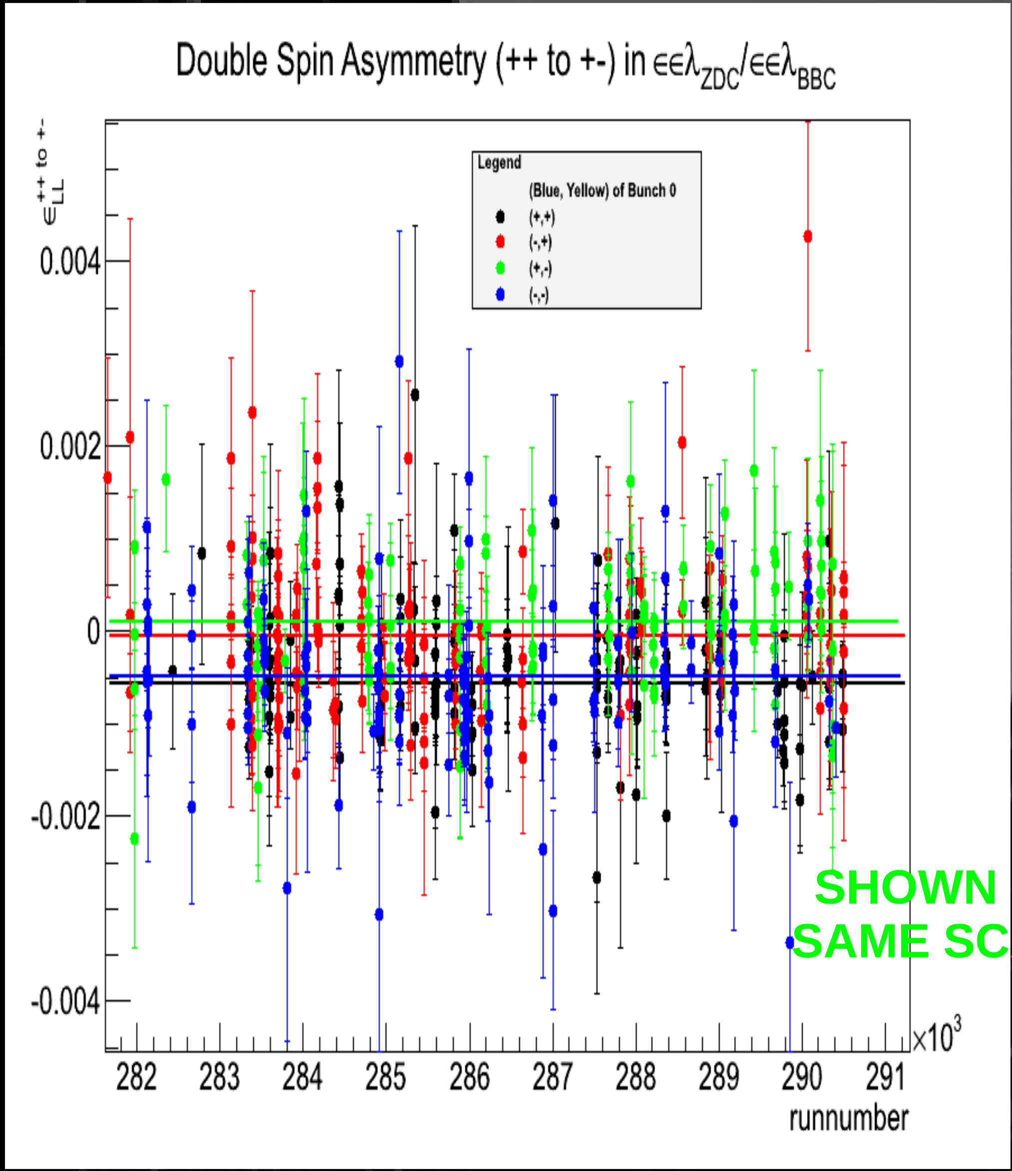


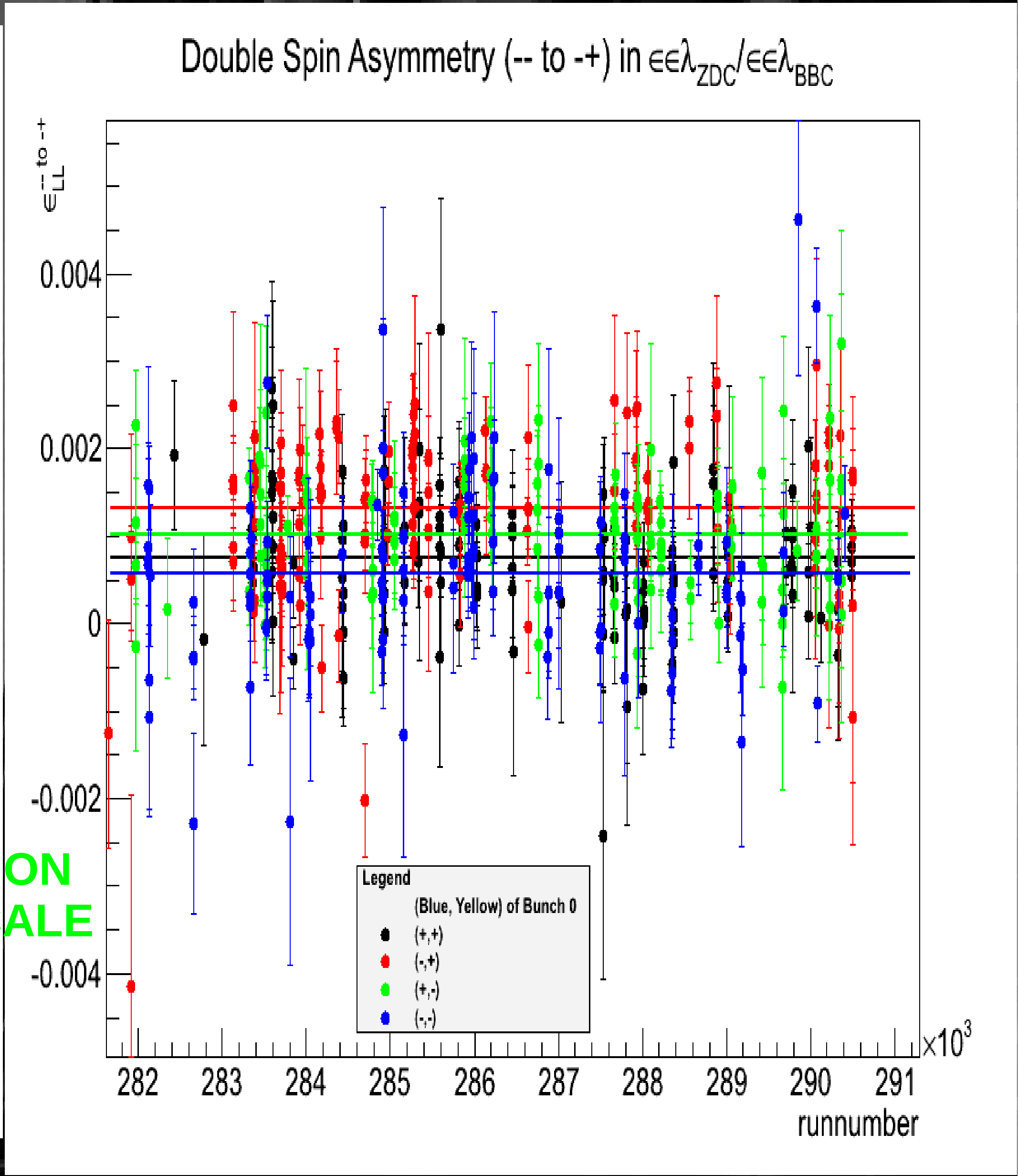
- Significant A_{180}, but also an A_{PV}
- A_{LL}s should fall on lines such as these from the simulation:





Run09: A_{PV}, A_{LL}(++ to +-), A_{LL}(-- to -+)





SHOWN ON SAME SCALE