Relative Luminosity: Systematic Uncertainty Studies

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PHENIX

Outline

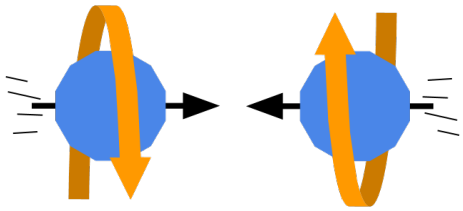
- Why RL studies?
- Intro to RL and systematic uncertainty
- Counting at higher rates
- Some results from 500/510 GeV
- Run12 200 GeV angle scan:
  - Beam geometry
  - A_N model
  - Simulation
  - EXPERIMENT and results
  - Future prospects
- Run13 plan preview

Historical Results - Why Work on This?

Run, $\sqrt{s}$	σ_{stat} π^0 A_{LL} smallest uncert. p_T bin	σ_{syst} RL
2005, 200 GeV	13e-4	2.5e-4
2006, 200 GeV	8.2e-4	7.5e-4
2009, 200 GeV	8.2e-4	14e-4

If this is due to a physics asymmetry, it should be constant year to year. Typical uncertainty on this number ~2.5e-4, so it not consistent.

What is a Relative Luminosity?



- e.g., in collisions with longitudinal spin (helicity), we measure asymmetries in the production of a particle

$$A_{LL} = \frac{1}{P_B P_Y} \left(\frac{N_{\pi^0}^{same} - R N_{\pi^0}^{opposite}}{N_{\pi^0}^{same} + R N_{\pi^0}^{opposite}} \right), R = \frac{L^{same}}{L^{opposite}}$$

- Here "same" are both "++" and "--" bunches, "opposite" are "+-" and "-+"
- R is the relative luminosity
  - because it is a ratio, we can construct it from measured counts in any detector that sees no spin asymmetry

How Do We Measure the Systematic Uncertainty on Relative Luminosity?

- i.e., what if our relative luminosity detector DOES see some spin asymmetry?
  - We use our minimum bias BBC (Beam Beam Counter) to measure R
  - ...and compare it with a detector past the DX magnetic field
    - ZDC: Zero Degree Calorimeter, no charged particles
  - We then assume the different physics they sample can't have the same asymmetry
  - Compare the two results to get the systematic

$$P_B P_Y A_{syst} = \epsilon_{syst} = \frac{\left(\frac{N_{ZDC}}{N_{BBC}}\right)^{same} - \left(\frac{N_{ZDC}}{N_{BBC}}\right)^{opp}}{\left(\frac{N_{ZDC}}{N_{BBC}}\right)^{same} + \left(\frac{N_{ZDC}}{N_{BBC}}\right)^{opp}}$$

How Can We Miscount?

- 500 GeV running brings higher intensities, which means higher rates and more problems
- With our minbias detectors, it is very easy to

- Undercount (in high multiplicity environments)

- Count what you don't want to ("singles" background)

ϵϵλ Method

more correct version of simple Poissonian rate correction:

Event Rate

$$P(k_S = 0) = e^{-\epsilon_S(\lambda+\lambda_S)}$$

Prob of registering hit in the detector

$$P(k_N = 0) = e^{-\epsilon_N(\lambda+\lambda_N)}$$

North-Only Event Rate, e.g. for Noise

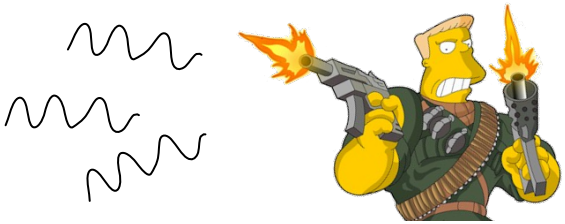
Need to measure correlation (e.g. "OR" of arms)

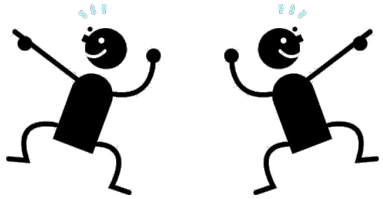
$$P(k_N = 0 \cap k_S = 0) = e^{\epsilon_N\epsilon_S\lambda-\epsilon_N(\lambda+\lambda_N)-\epsilon_S(\lambda+\lambda_S)}$$

From These Three Can Extract $\Rightarrow \epsilon_N\epsilon_S\lambda$

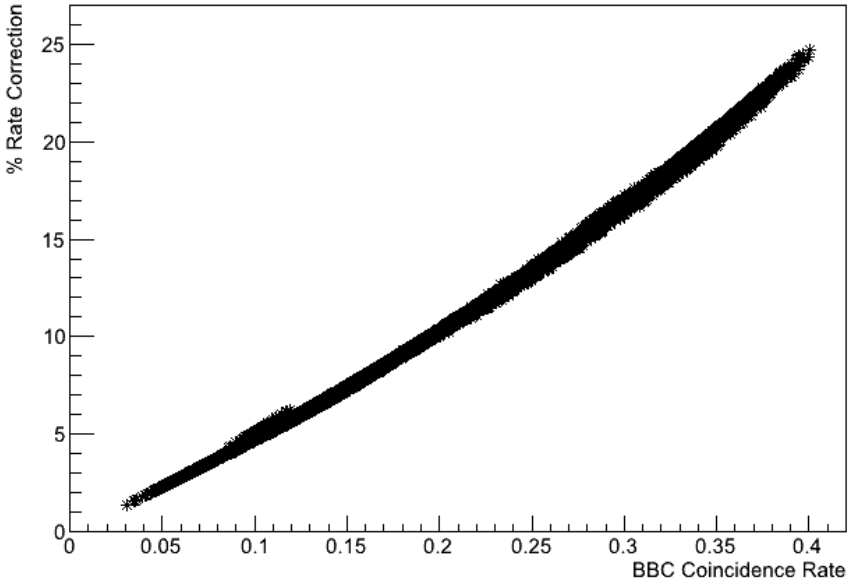
"Free" of rate effects AND some backgrounds!

Rate Correction Dependence on Rate

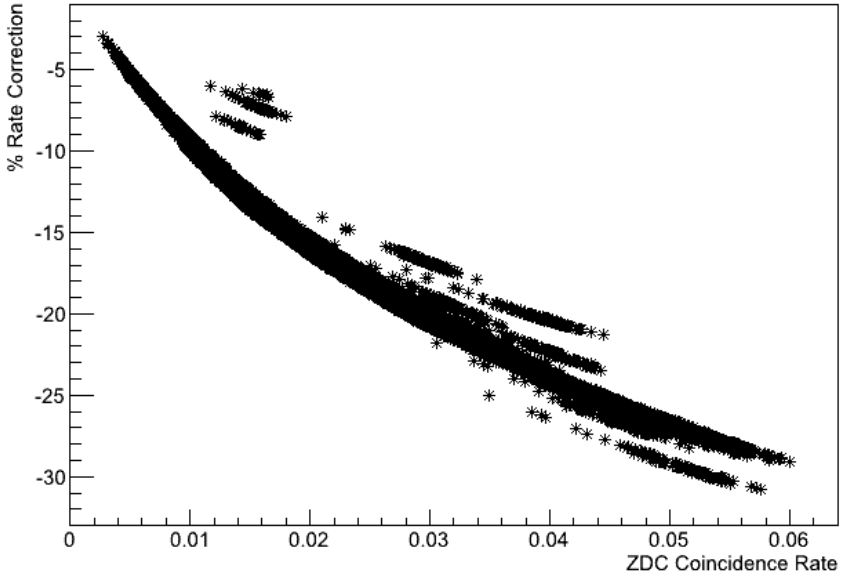




BBC Rate Correction Dependence on .... Rate, Run11, 500 GeV



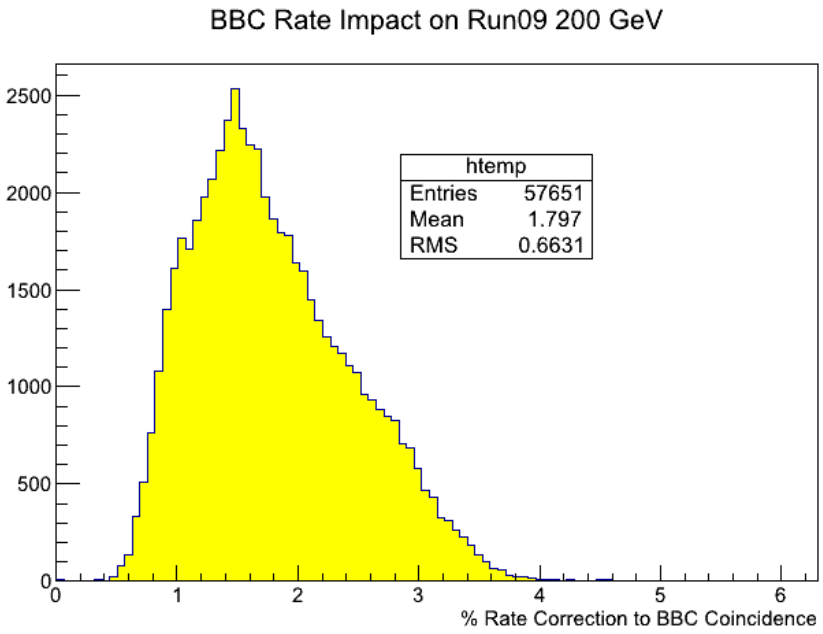
ZDC Rate Correction Dependence on .... Rate, Run11, 500 GeV

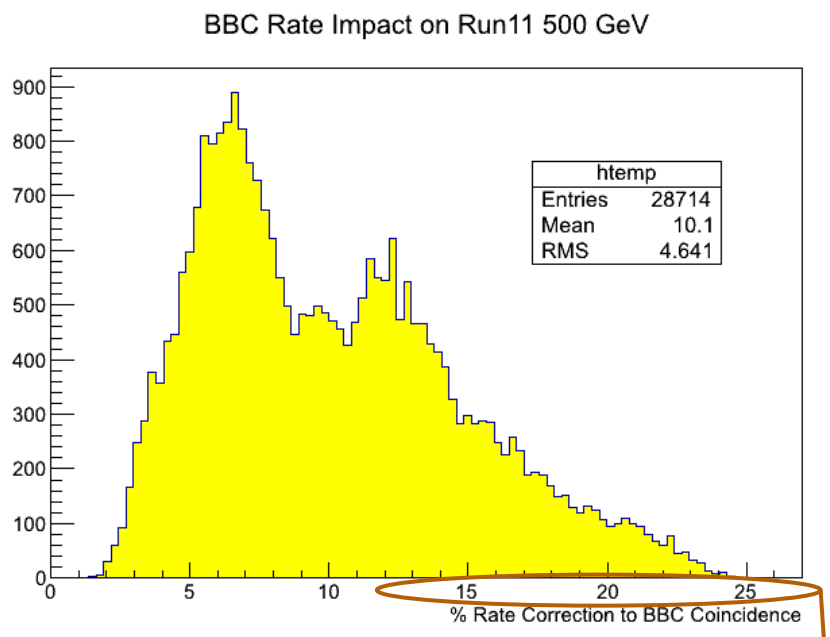


- We see clearly how miscounting (under in the case of BBC and over in the case of ZDC) increases with rate

Rate Corrections in 200 vs. 500 GeV

One entry in histogram for every beam crossing in every run



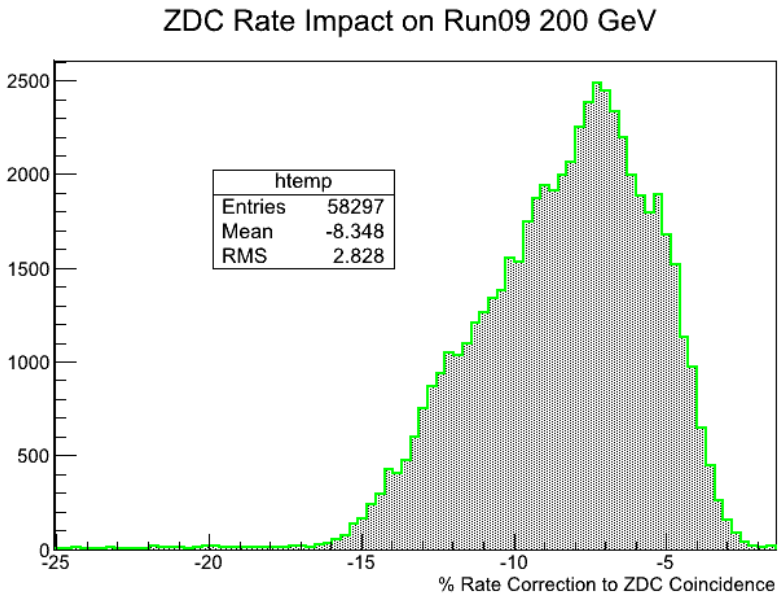


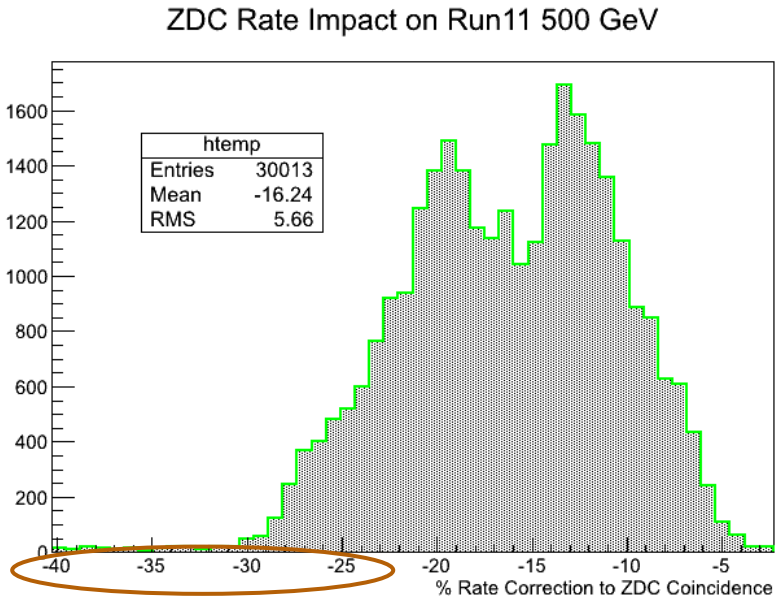
Significantly larger corrections at 500 GeV.
BBC undercounts due to multiple collisions.

Note drastic change in scale!

Rate Corrections in 200 vs. 500 GeV

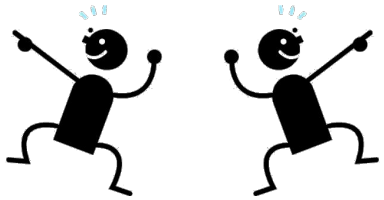
One entry in histogram for every beam crossing in every run



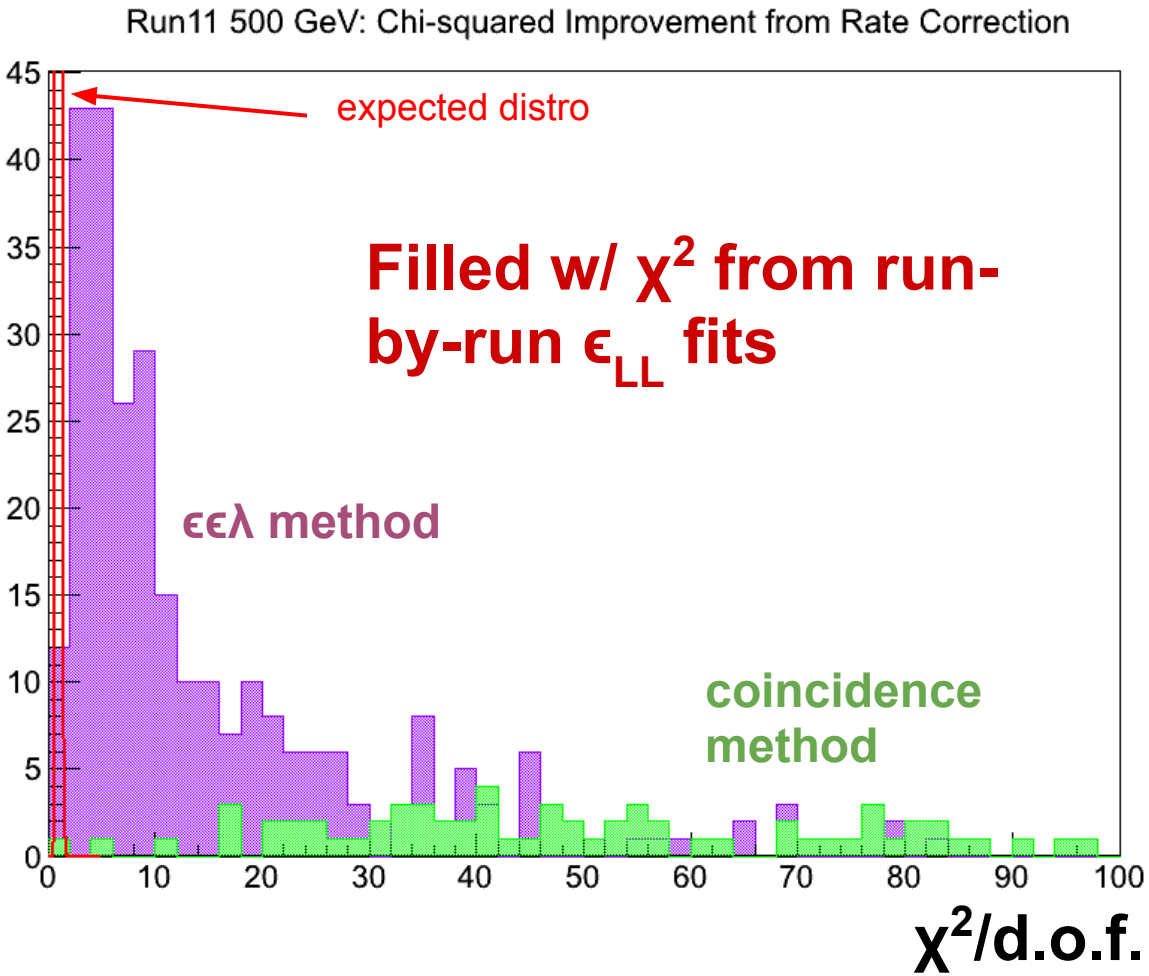


Note drastic change in scale!

ZDC overcounts due to high accidental coincidences of single-sided events.

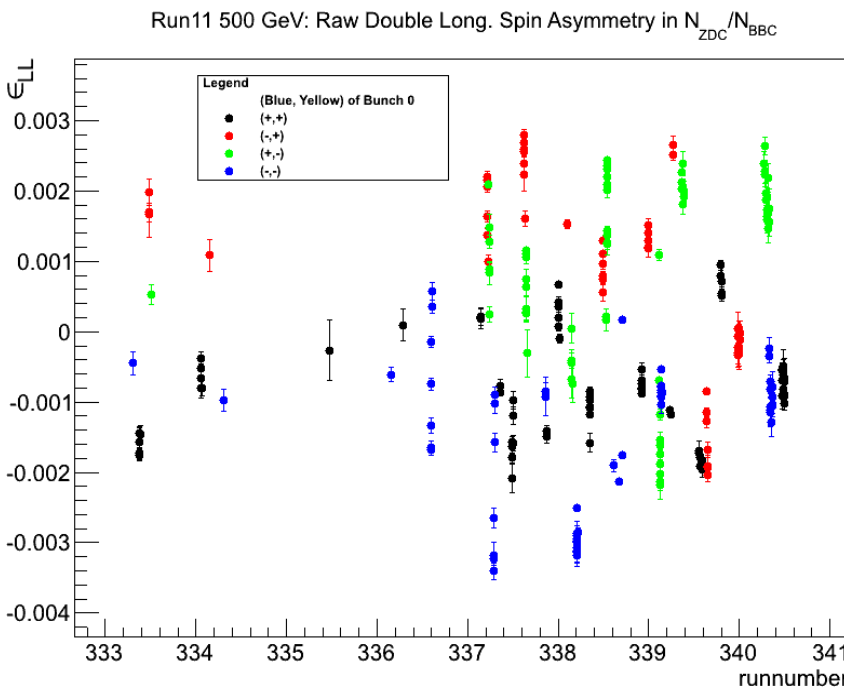


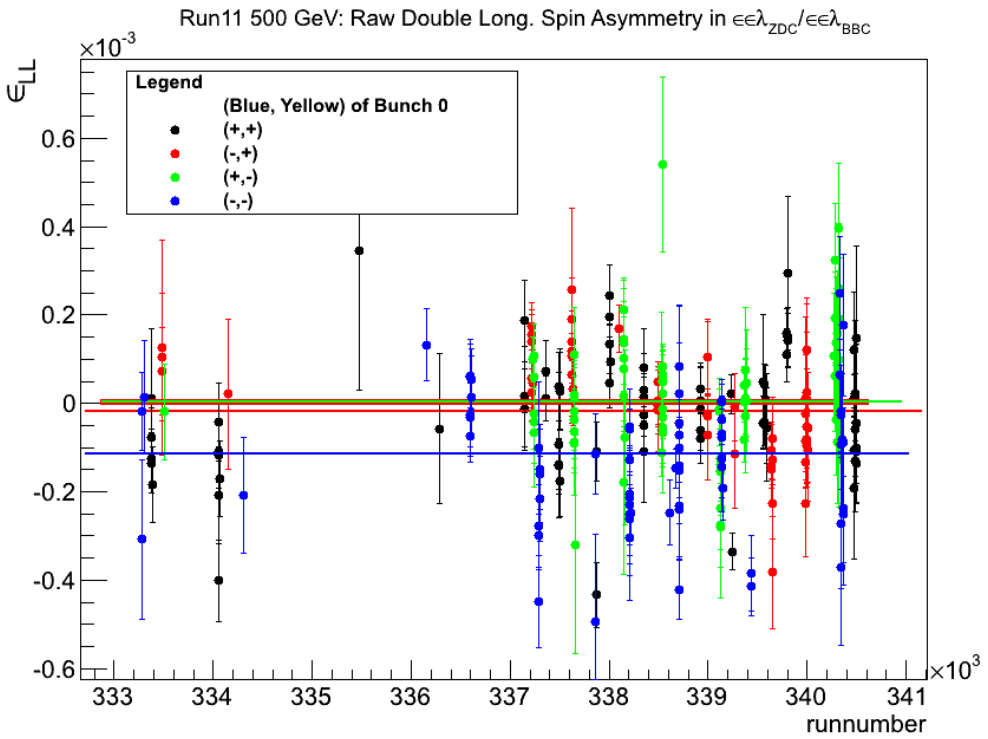
Run 11 500 GeV Results
Chisquared Improvement



- Measurement becomes possible again
- Not included:
  - Polarization
  - Bunch Width
  - / z-dependent efficiency effects

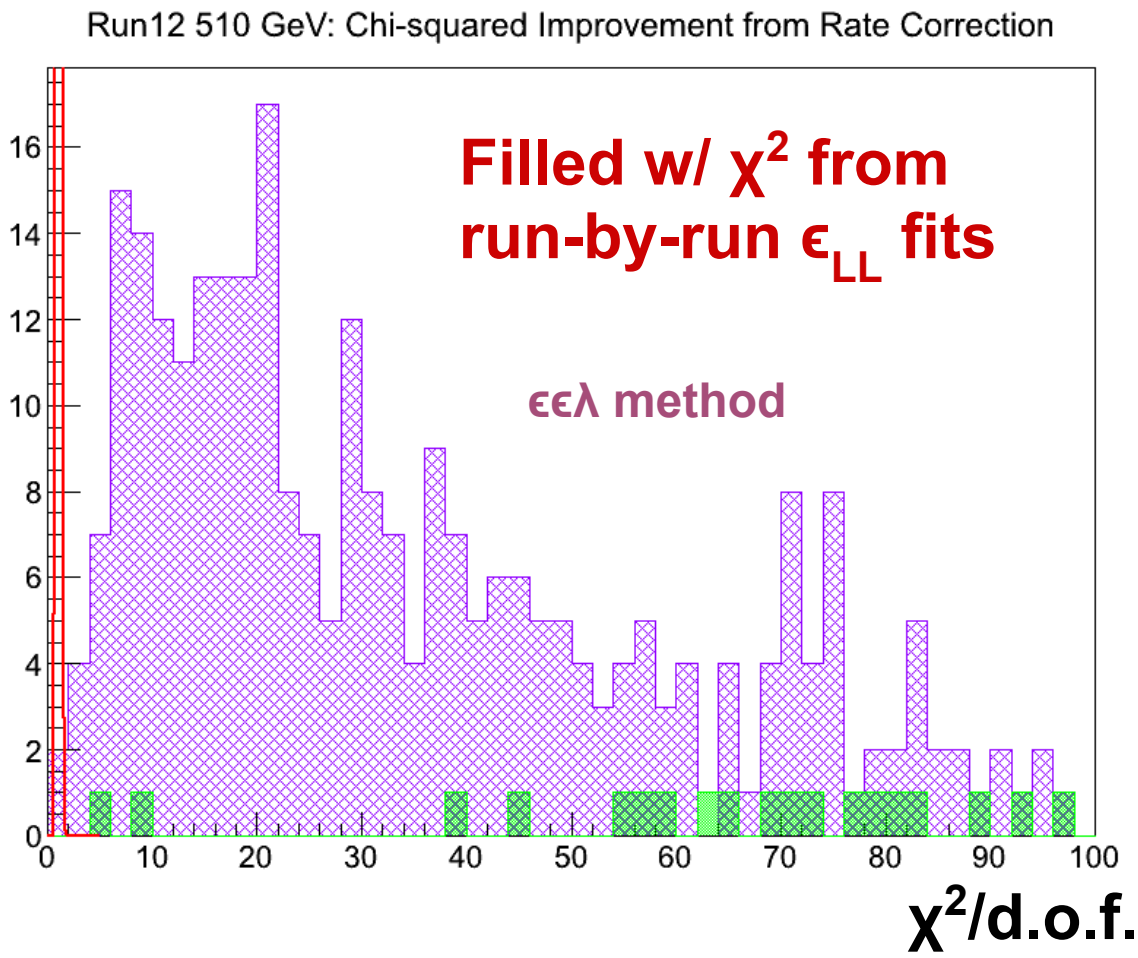
Run 11 500 GeV Results
Raw Asymmetry Results





- **Ongoing Work**

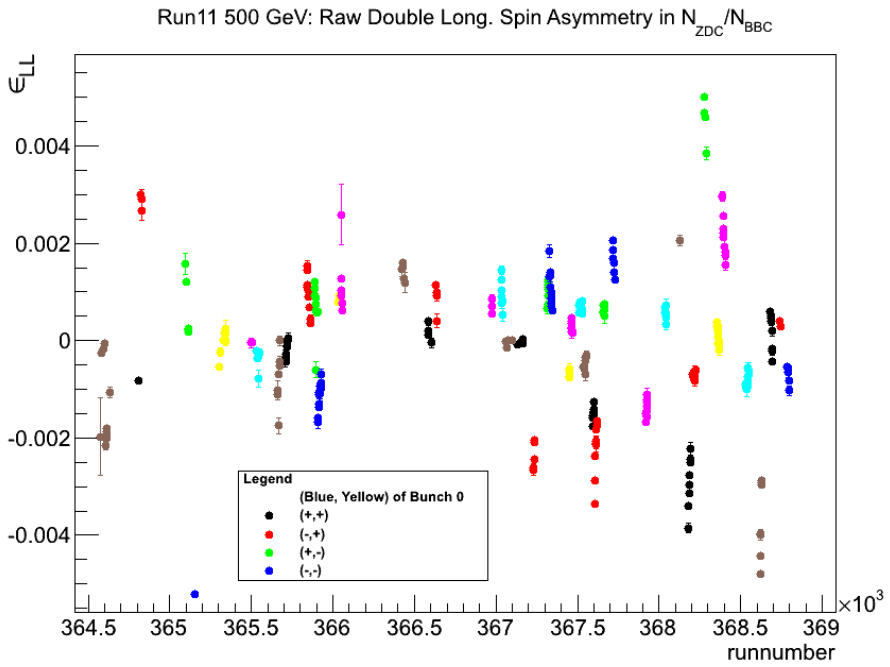
Run 12 510 GeV Results
Chisquared Improvement

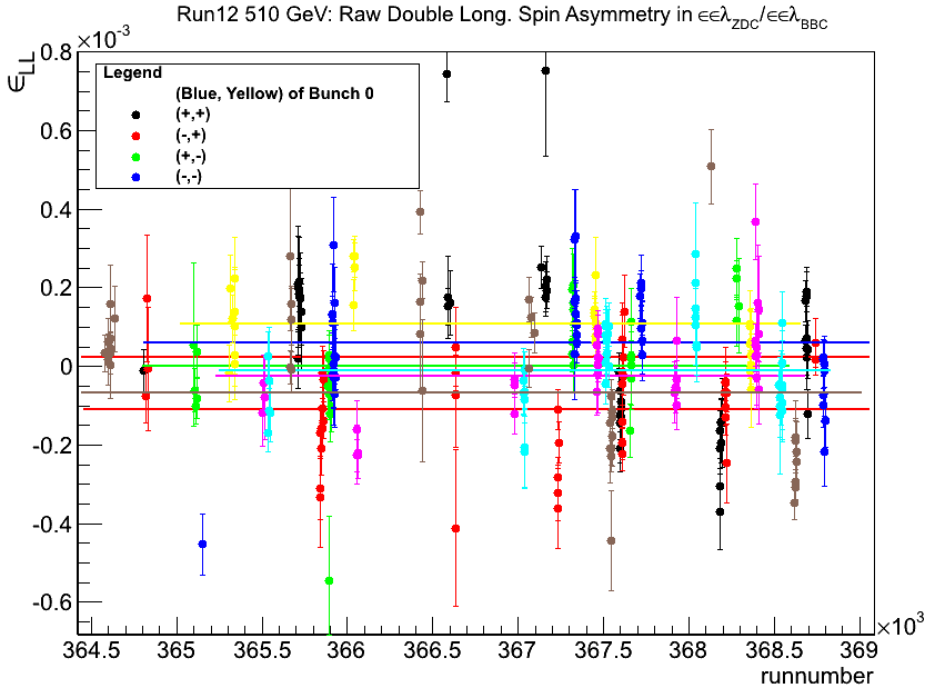


- Even more funny business?

coincidence method →

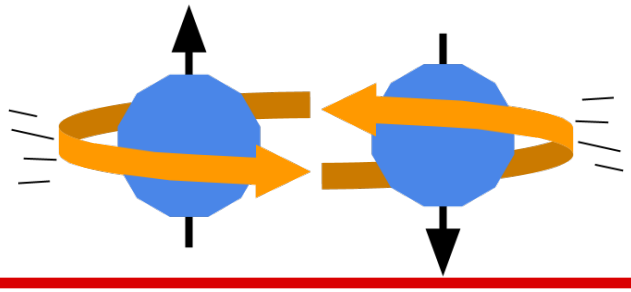
Run 12 510 GeV Results
Raw Asymmetry Results

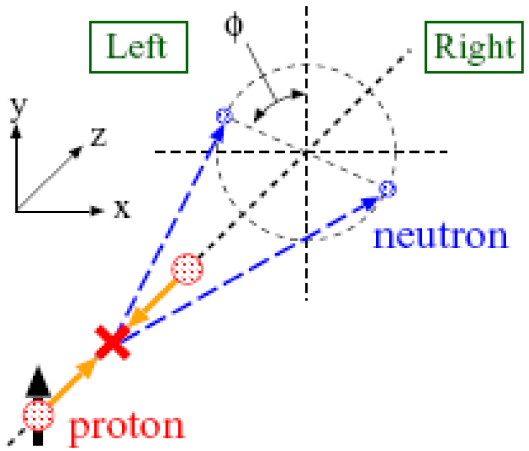




- **4 new spin patterns!!!**
- **Ongoing Work**

Transverse Spin

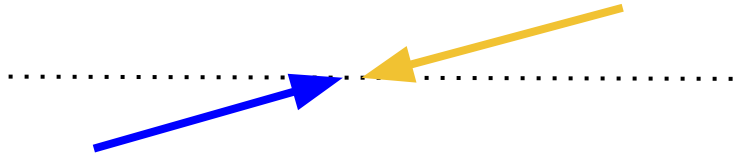




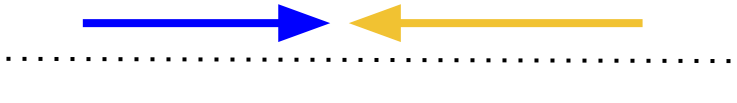
- Run12 200 GeV is the latest transverse spin Run
  - One notable effect in transversely polarized collisions is a phi-dependent asymmetry A_N
    - We use the magnitude of this asymmetry in neutron production to determine our overall polarization direction
  - Our hypothesis: Maybe A_N coupled with some geometric effect could be faking other asymmetries.
    - Hence a beam angle scan for Run12 200 GeV was planned

Beam Geometry

- Beams traverse IRs in "zero" magnetic field region
  - straight paths
- Intersection geometry of beams can be decomposed into three components (x 2 planes)
  - Collinear Angle:

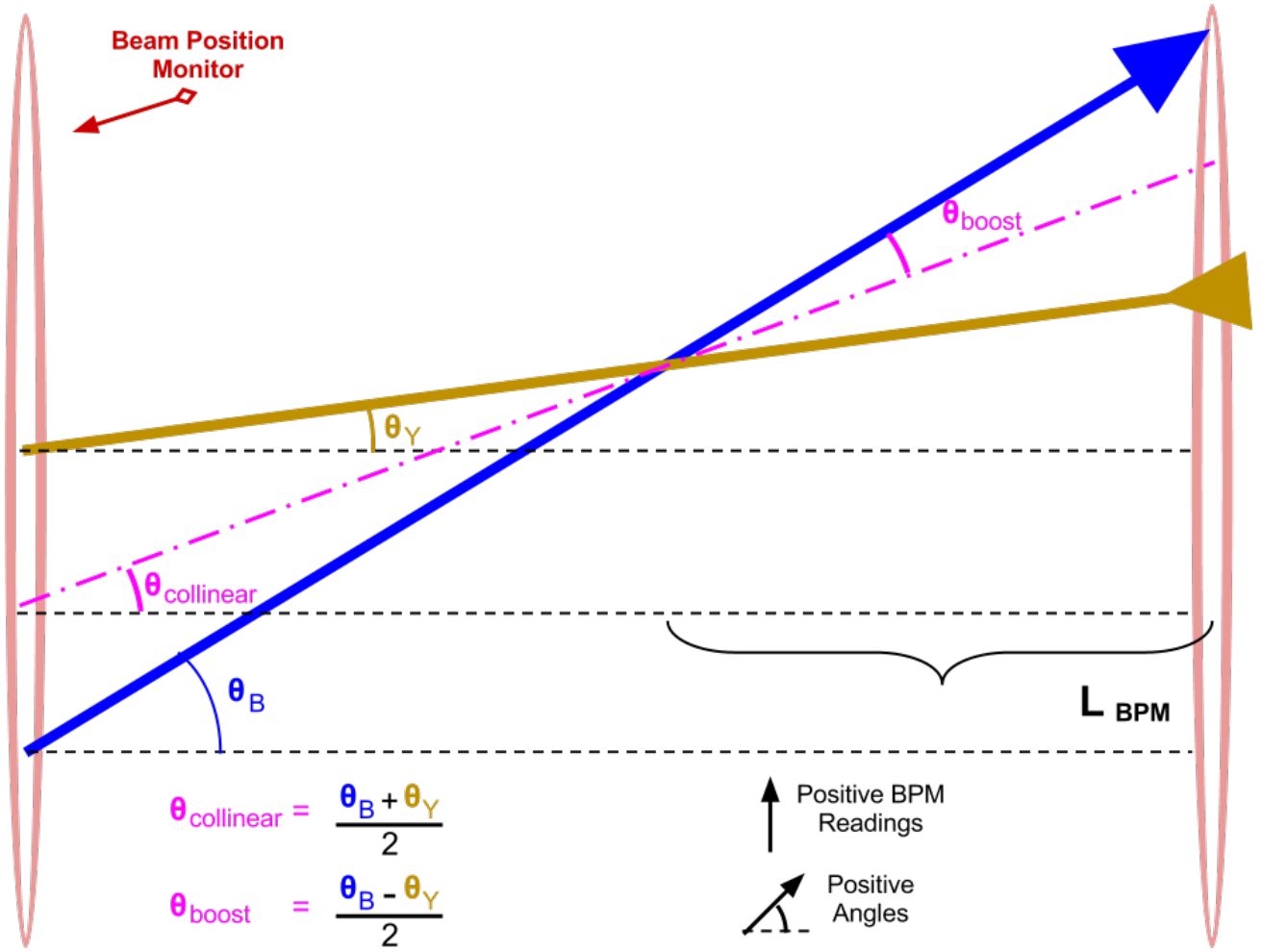


  - Offset:

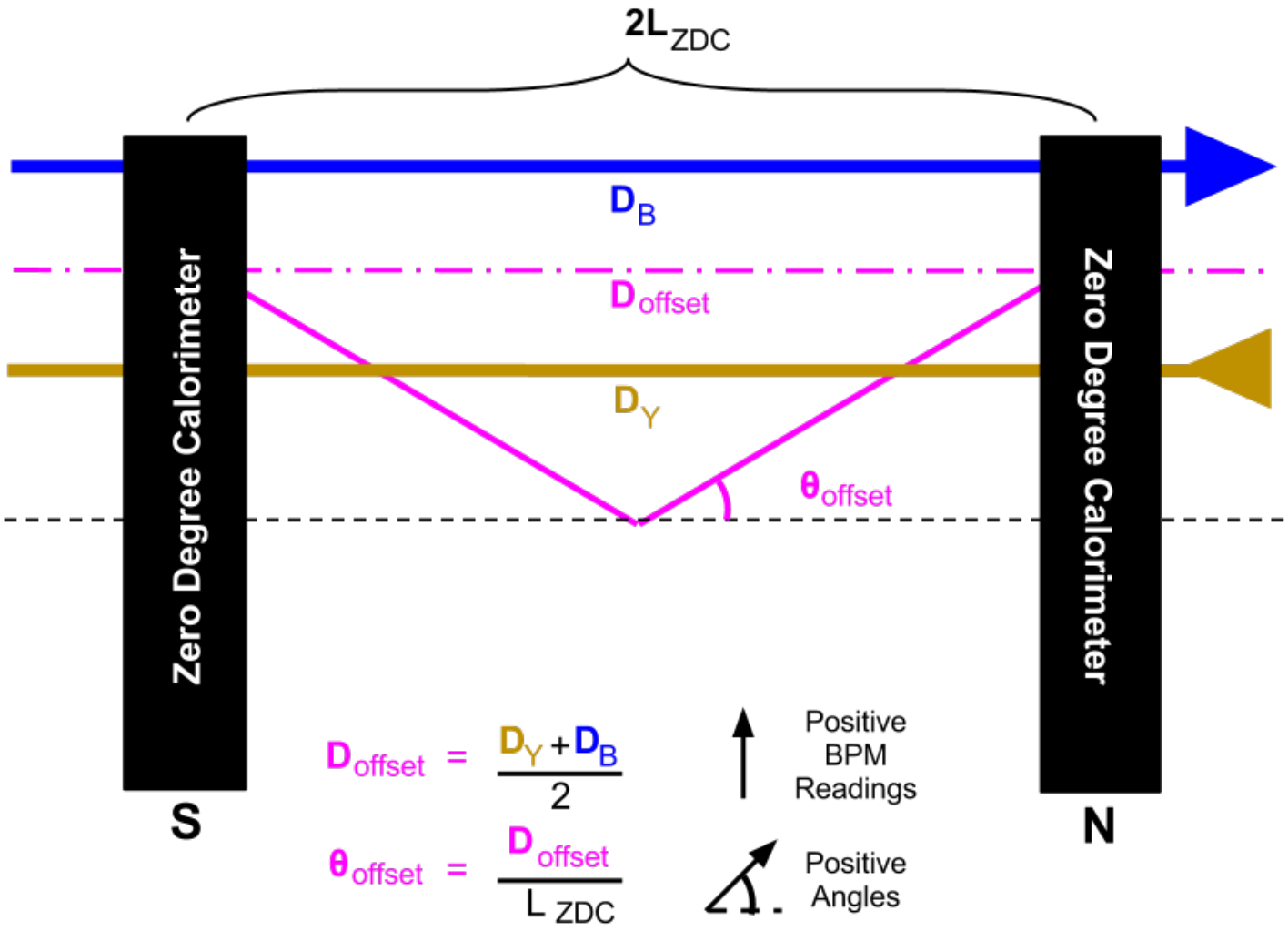


  - Boost:

Precise Angle Definitions - Collinear/Boost

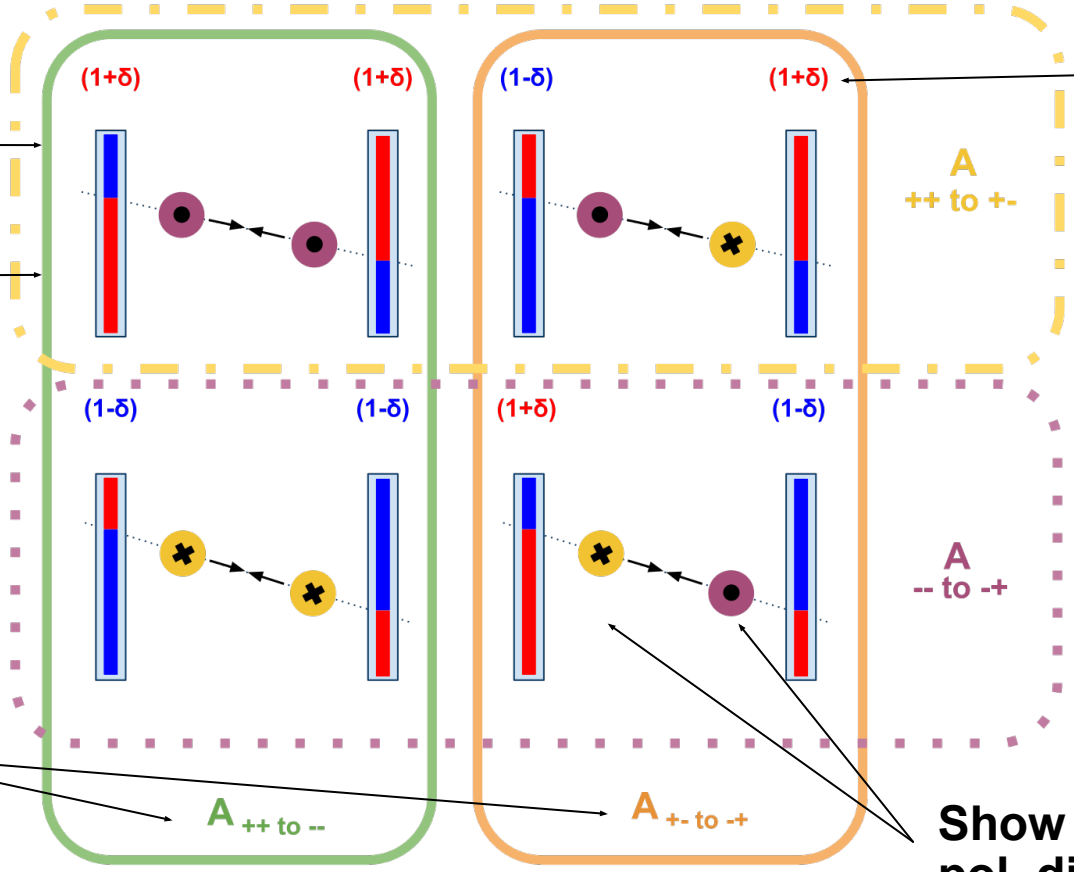


Precise Angle Definitions - Offset



Model: Case of Collinear Beam Angle

Fewer
-or-
More
Particles
(from A_N)



Acceptance modification factor

Different Asymmetries

Show transverse pol. direction

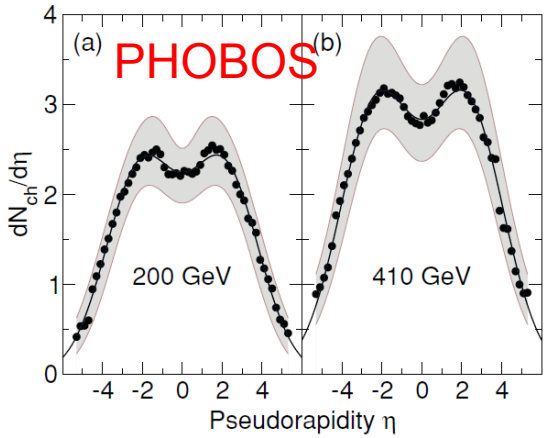
Predictions of Model

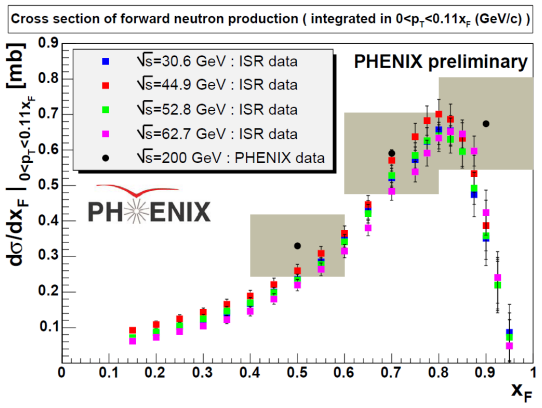
	$\epsilon_{++ \text{ to } --}$	$\epsilon_{+- \text{ to } -+}$	$\epsilon_{++ \text{ to } +-}$	$\epsilon_{-- \text{ to } -+}$
Collinear Angle	$= (P_B + P_Y)\ \delta$	$= 0$	$= P_Y\ \delta$	$= -P_Y\ \delta$
Offsets	$= 0$	$= (P_B + P_Y)\ \varepsilon$	$= -P_Y\ \varepsilon$	$= P_Y\ \varepsilon$
Boosts	$= 0$	$= (P_B + P_Y)\ \varepsilon$	$= -P_Y\ \varepsilon$	$= P_Y\ \varepsilon$

- Key Feature: linear dependence on polarization
- δ, ε: acceptance modification factors, functions of angle, offset, or boost

Simulation Details

- Toy Monte Carlo of colliding beams
  - Charged particles for the BBC produced according to previously measured distributions
  - Neutrons for the ZDC according to previously measured distributions AND A_N
  - Collided at any angle/offset/boost





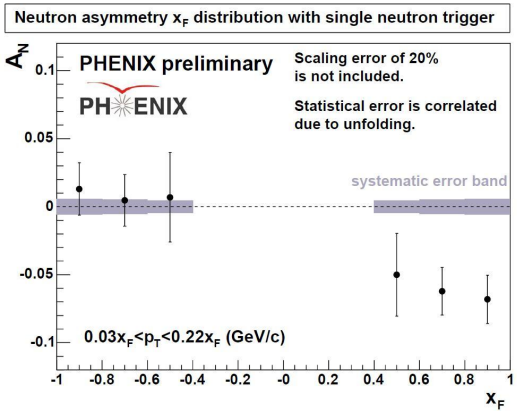
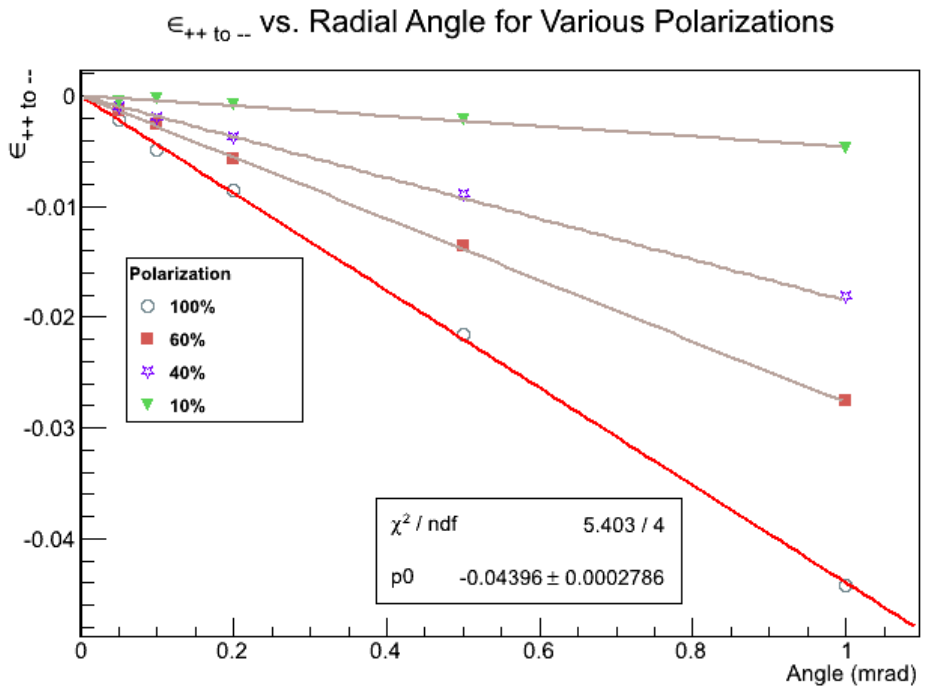


FIG. 29. (Color online) Charged-particle multiplicity $dN_{ch}/d\eta$ shown for 200-GeV (a) and 410-GeV (b) pp inelastic collisions.

Predictions of Simulation (Collinear)



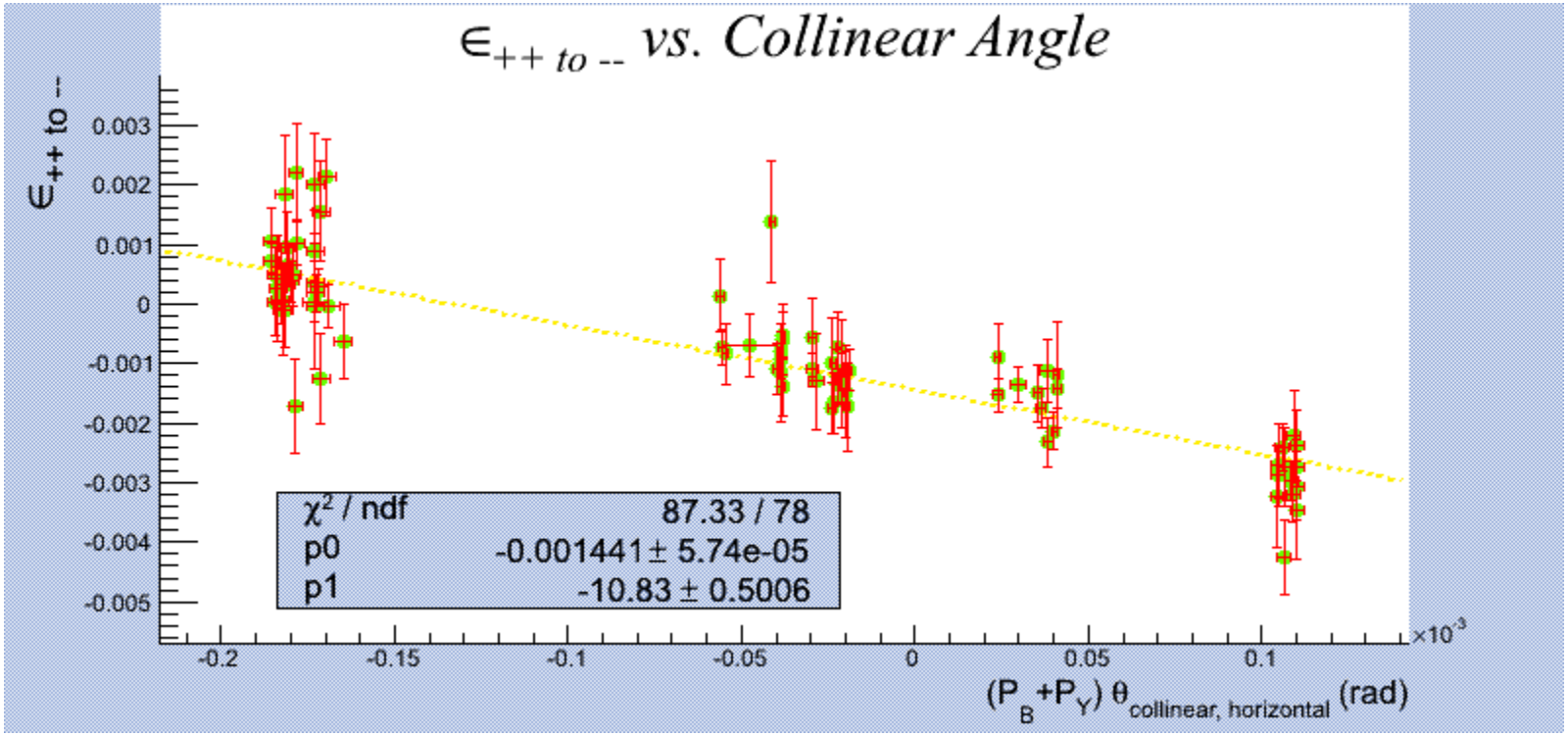
- Key prediction:
  - linear relationship between asymmetry and angle/offset/boost
- Linear dependence on pol confirmed
  - only red line is fit, rest are scaled by input polarization
- Predicted slope for ANY polarization:
  - $\epsilon_{++\text{ to }--}$ = **-7.0** (PB + PY) **θ** (in rad)
    - using fraction of neutrons in the ZDC = 0.32 from PYTHIA

Experiment: Angle Scan Results

- In Run12 200 GeV, we managed to arrange for a short beam experiment in the PHENIX IR
  - running concurrently with PHYSICS data taking
- Q: What was varied?
  - A: Horizontal collinear beam angle
  - which meant that $\epsilon_{++ \text{ to } --}$ ("parity violating") should be most strongly affected
- How many steps?
  - 4 angle steps, including "nominal"
- Automatic orbit correction off

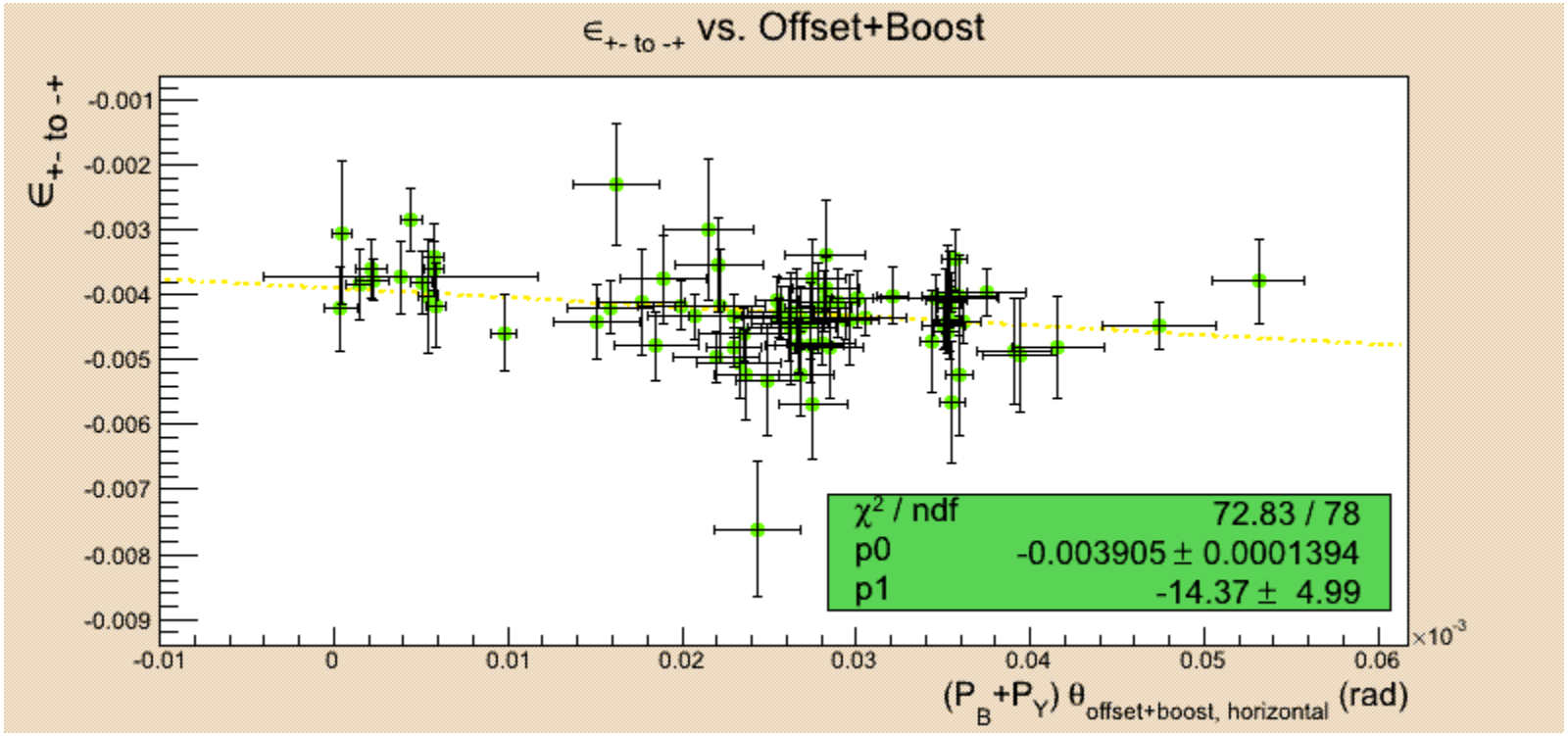
Result: $\epsilon_{++\ to\ --}$ ("Parity Violating")

- Note slope and compare with rest



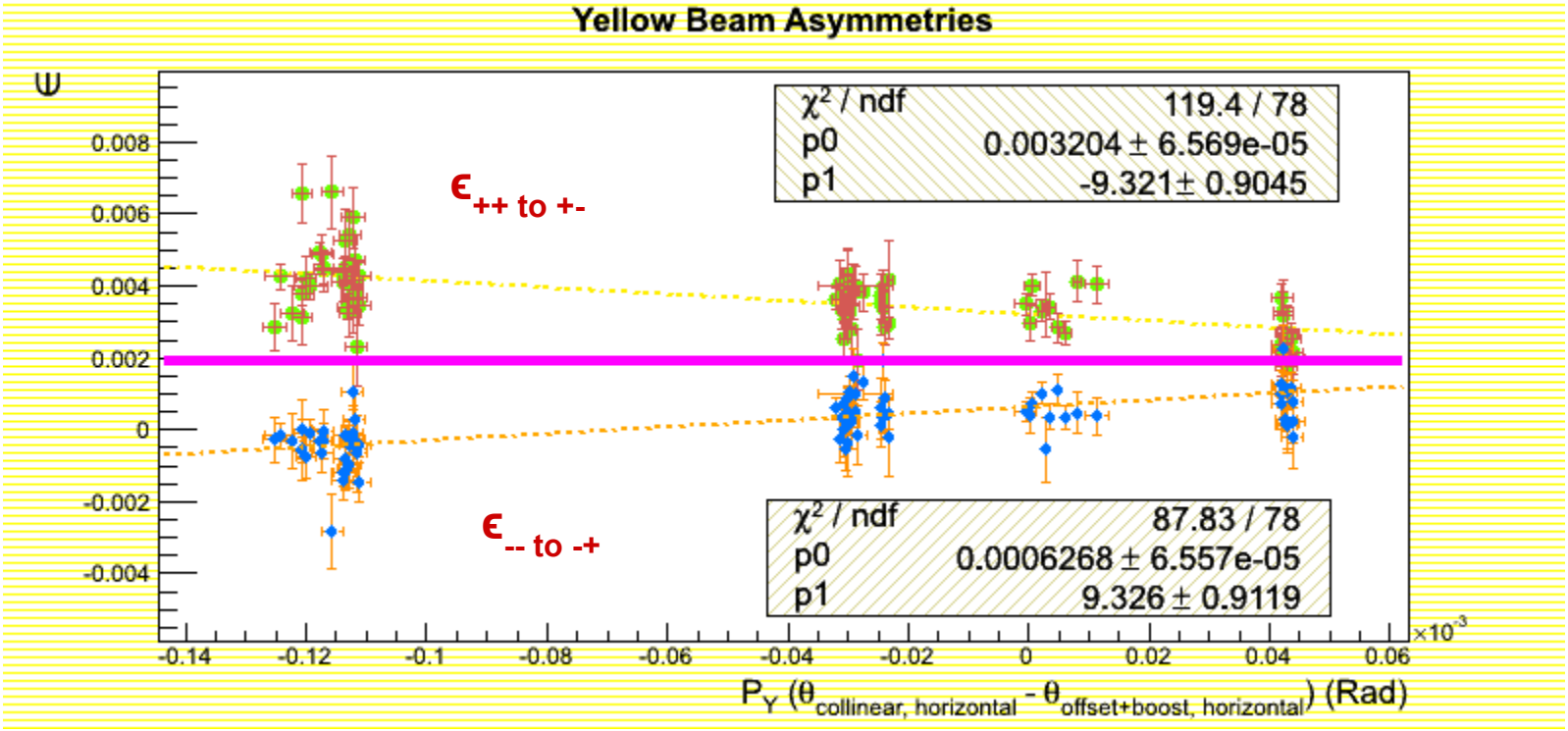
Result: $\epsilon_{+- \text{ to } -+}$ ("A 180° Rotation")

- Should not have changed much during scan
  - its dependence is on boosts and offsets



Result: Yellow Beam Asymmetries ($\epsilon_{pp\ to\ pm}$, $\epsilon_{mm\ to\ mp}$)

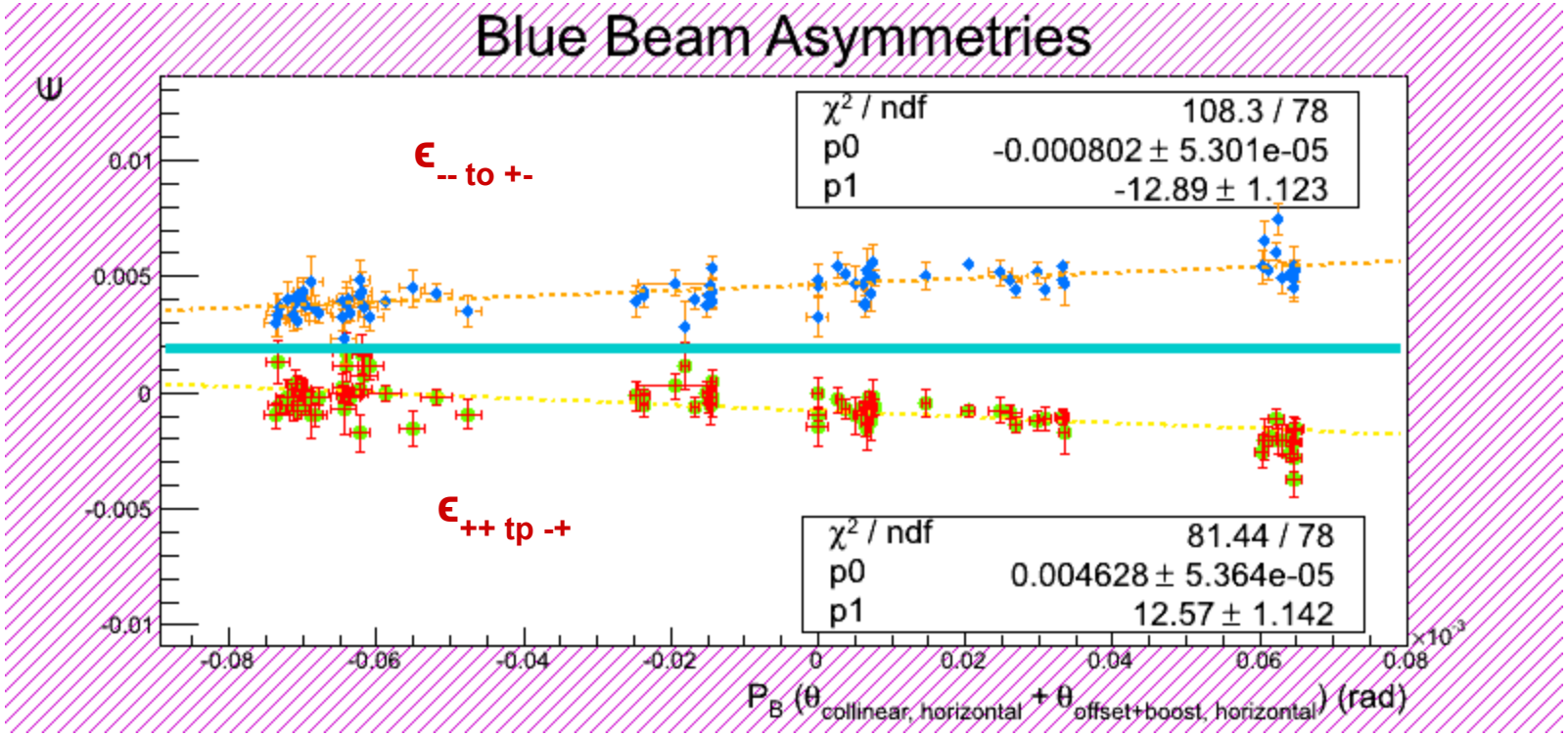
- Under model, should be equal and opposite



- Slopes equal and opposite, but not intercepts

Result: Blue Beam Asymmetries ($\epsilon_{pp\ to\ mp}$, $\epsilon_{mm\ to\ pm}$)

- Under model, should be equal and opposite

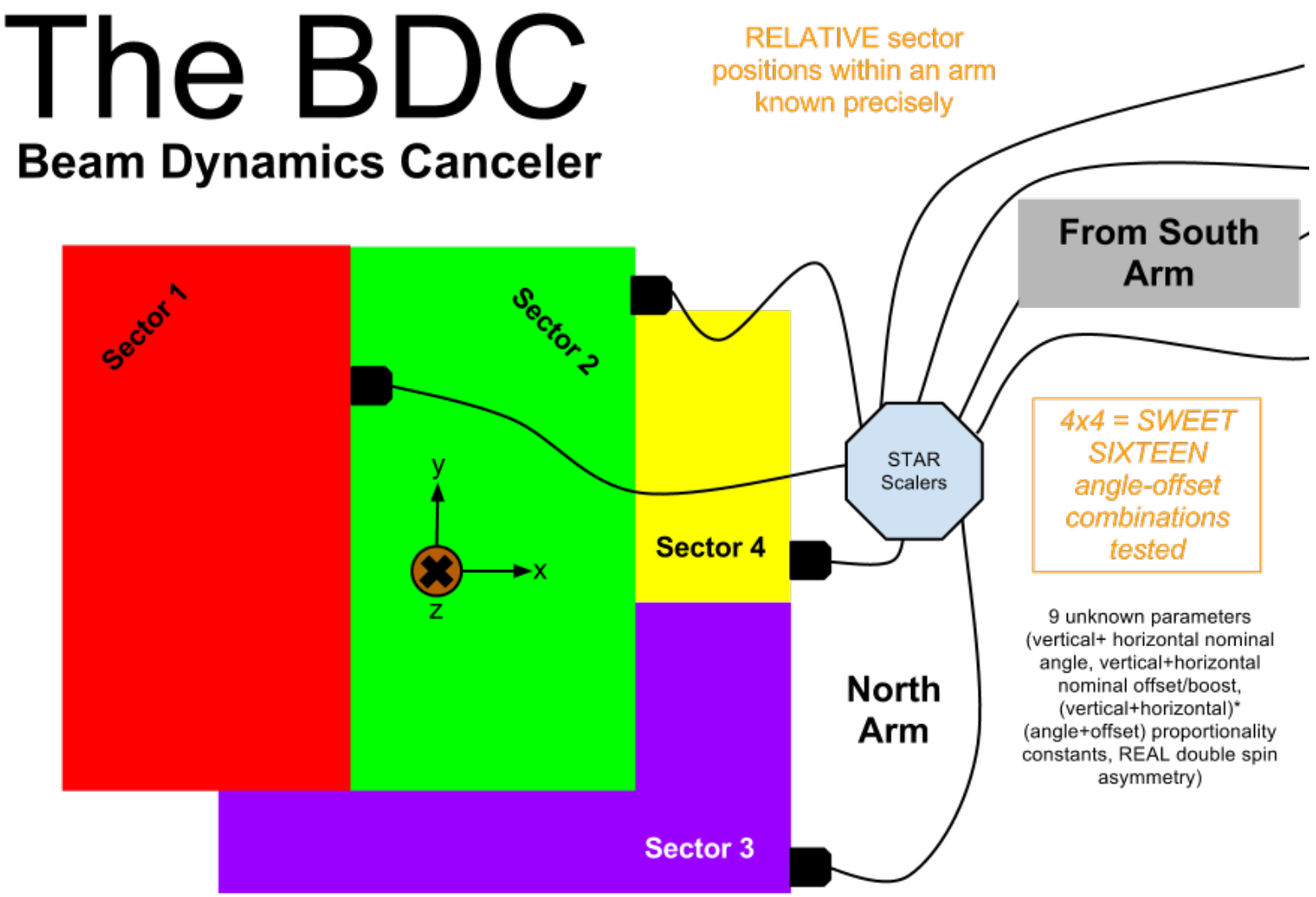


- Slopes equal and opposite, but not intercepts
  - as in yellow, average ~2e-3

Unknowns for Future Studies/Investigations

- polarization structure
  - can couple with offsets/angles to create additional effects
- *offset* scan (especially in vertical direction)
  - ZDC detector shifted 1.2 cm in vertical w.r.t the nominal beam axis
  - 1.2 cm at the 18m ZDC translates to 666 μrad angle
    - angle scan had a range of ~300 μrad
    - could be in a non-linear region
- Check for effects in the BBC
  - can be done by combining offsets (which move on BBC and ZDC equally) and angles (negligible at the BBC)

Plans for Run 13: BDC



Conclusions

- With novel rate/background corrections, we can measure RL/RL systematic uncertainty in 500 GeV running
- New studies give us insight into how different asymmetries couple
  - Can explain seemingly non-physical (180 degree rotational) and fantastical (large parity violating) asymmetries
- More studies needed in the future
  - if we can get the beam time
  - "BDC" would get us part way there, and allow us to obtain ample angle/offset statistics in long. running